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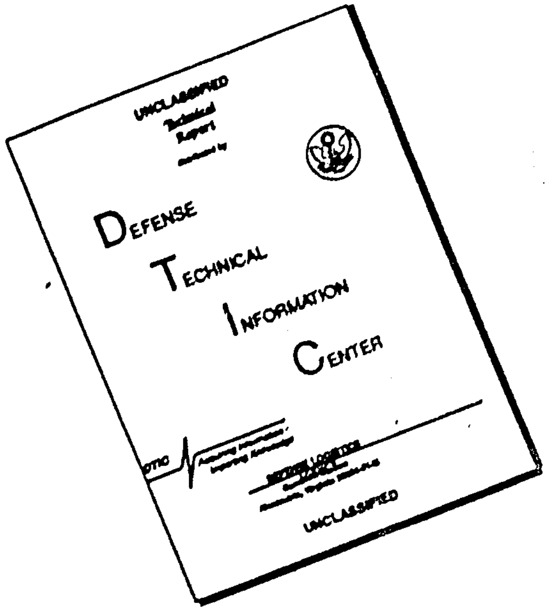

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RADC-TDR-63-403
FINAL REPORT

A STUDY AND INVESTIGATION OF THE OPERATIONS CENTRAL AN/MSQ-16(XW-2)

TECHNICAL DOCUMENTARY REPORT NO. RADC-TDR-63-403

December 1963

Vulnerability Reduction Branch
Rome Air Development Center
Research and Technology Division
Air Force Systems Command
Griffiss Air Force Base, New York

Project No. 4557, Task No. 6

(Prepared under Contract No. AF30(602)-3095 by Tridea Electronics, Inc., South Pasadena, California.)

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FOREWORD

This report was prepared by a Tridea, Inc., Engineering group consisting of P. M. Brown, Project Engineer and responsible for the antenna and pedestal design; L. J. Meyers, responsible for data processing; D. McGregor, responsible for receivers and calibration; S. Howard, responsible for the control console; and K. Holtz, responsible for operational aspects and equipment siting. In addition, A. G. Van Alstyne provided aircraft flight data and editing of the final report.

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Key Words: Electromagnetics; antenna; instrumentation.

ABSTRACT

This report describes the detailed requirements of the Operations Central AN/MSQ-16 (XW-2) equipment to be installed at the Verona Test Site at the Rome Air Development Center, for the purposes of making in-flight antenna pattern measurements and to provide a general purpose facility to make spectrum signature measurements on a wide variety of radiating weapon systems. The various expected signal sources are analyzed and the required equipment performance in terms of antenna gains and receiver sensitivities is specified. An analysis of means of providing a passive tracking capability is made and it is concluded that an r-f differencing monopulse type tracker can provide the required angle tracking performance over the r-f tuning range of 0.1 KMc to 18 KMc, with this range divided into six bands.

Various receiver and calibration systems are analyzed and it is concluded that the receiver tuning units and calibration generators should be located within the antenna pedestal. Transmission of signals to the main equipment location can then be made at i-f frequencies.

The required signal data processing is analyzed from the standpoint of two system configurations; one employing a raw data recording system which permits data processing at any time after flight data is taken, and one employing a general-purpose digital computer for real-time data processing during the flight. It is concluded that the latter configuration has major advantages and will not appreciably increase the equipment cost.

PUBLICATION REVIEW

This report has been reviewed and is approved. For further technical information on this project, contact Mr. Merton E. Cook, EMCVM-4, Ext. 27281.

Approved: Merton E. Cook
MERTON E. COOK
Task Engineer

Approved: Samuel D. Zaccari
SAMUEL D. ZACCARI, Chief
Vulnerability Reduction Branch
Communications Division

FOR THE COMMANDER: Irving J. Gabelman
IRVING J. GABELMAN
Director of Advanced Studies

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Evaluation of Contractual Effort

This study effort is the first part of a two phase program to provide the Air Force with a capability of Airborne Spectrum Signature, which is unavailable at this time. The second part will provide a developmental model to be installed at the Verona Test Annex.

The developmental model will provide a modernized Operations Central with equipment capable of operating with all possible modulations, greater dynamic range, improved accuracies and designed for a greater reliability. Other improvements to be included will be automatic data recording for computer data read-out and real time data reduction, a passive tracking measurement system capable of both absolute and relative radiation measurements, and analysis equipment for the collection of spectrum signatures. The system will cover the frequency range from .1 to 18gc, but is designed in a building block configuration for future expansion to 100gc, infra-red and ultra-violet measurement, thus meeting the rapidly advancing state of the art program requirements. These measurements will be made on a real time radiated basis, resulting in instantaneous and direct readout capability of accurately measured parameters in support of the DOD Electromagnetic Compatibility Program. Related areas of support will be made in airborne spectrum signatures, Radio Frequency Interference Analysis, Radar Reflectivity Measurements and Dynamic Antenna Pattern Evaluation Programs.

Merton E Cook
MERTON E. COOK
Task Engineer

SECTION 1

INTRODUCTION

This is the final technical report of an engineering study to specify the detailed configuration of the Operations Central AN/MSQ-16 (XW-2) equipment. This study was performed by Tridea Electronics, Inc., South Pasadena, California, for the Rome Air Development Center under Contract AF 30 (602)-3095, in accordance with performance criteria established by Exhibit RADC-5111.

1.1 CONTRACT OBJECTIVE

The purpose of the contract is to study the requirements of the Operations Central AN/MSQ-16 (XW-2) equipment with the objective of defining a detailed equipment configuration which will perform the AN/MSQ-16 (XW-2) mission assignment. The AN/MSQ-16 (XW-2) equipment is to be a permanent installation at the Verona Test Site, a test facility of the Rome Air Development Center, Griffiss Air Force Base, New York. The purpose of the equipment is to provide a facility for the measurement of airborne antenna patterns and spectrum signature of radiating airborne systems. The initial equipment will provide an antenna and receiving system capable of operation over the frequency range of 0.1 KMc to 18 KMc, with an expansion capability for operation to 40 KMc. Specifically, the equipment is to provide the following:

1. High-gain antennas capable of receiving the expected signal sources.

2. A slaved tracking mode of operation, capable of slaving the receiving antennas to an external active radar tracker (AN/MSQ-1A or AFMTC Mod III).

3. A passive tracking mode, capable of passive tracking any signal source within its frequency range.

4. A calibration system capable of allowing the measurement of the absolute received signal levels.

5. A panoramic search and display mode capable of displaying all signals within the equipment frequency range.

6. A data processing system capable of coordinating the various signal parameters and performing the data processing and computation necessary to analyze and describe the radiation patterns in terms of aircraft coordinates.

7. A display and control console capable of providing control of the equipment, monitoring of selected signal parameters and means for manual entry of various identification data.

In addition to the study of the equipment requirements, another contract objective was to survey various available items of electronic equipment which could be incorporated into the Operations Central to meet the system requirements. This survey had the objective of providing the desired performance at a minimum development cost. In order to meet this requirement, a brief specification describing the required performance of the major subsystems was prepared and submitted to known manufacturers of these items. The results of this survey are contained in Section 6 of this report.

Section 2 of this report contains the results of the equipment requirement study. Section 3 contains a discussion of operational considerations and of siting and collimation problems. Section 4 contains a detailed description of a system which is considered an optimum equipment configuration, and Section 5 contains a discussion of the system's future expansion capability. The remaining section contains a report bibliography.

Appendix I contains a discussion of the system reliability, and Appendix II contains a discussion of maintainability considerations. Appendix III describes a method of computing orientation of an RF Vector.

SECTION 2

EQUIPMENT REQUIREMENTS AND TECHNIQUE INVESTIGATIONS

This section summarizes the investigations of basic techniques which might be used to perform the functions required. Each basic function is discussed separately by first developing the operating parameters and then describing the available techniques.

2.1 ANTENNAS

The antenna requirements of the AN/MSQ-16 (XW-2) are determined by a number of interrelated system requirements. From the standpoint of the pedestal and r-f transmission requirements it is obviously advantageous to cover as large a frequency band as possible. However, other factors, such as passive tracking, the limited tuning range of available receivers and calibration requirements may make it desirable to restrict the antenna bandwidths to provide a less complex and costly system.

At the present time, a single antenna is not available which will cover the complete frequency coverage of the AN/MSQ-16 (XW-2). This then requires that the antenna system be divided into a number of frequency bands. The manner in which the full frequency coverage is divided will be dependent in part upon the state of development of available antennas and other system considerations as previously indicated.

2.1.1 Required Antenna Performance. - It is first of interest to investigate the required antenna performance, in terms of gain and beamwidth as a function of the operating r-f frequency. Once this has been determined, various antenna configurations can then be investigated.

In order to determine the required antenna performance, it is first necessary to make certain assumptions as to the characteristics of the signal source for which measurements are to be made. In order that these assumptions remain valid for all the expected signal types for which the AN/MSQ-16 (XW-2) is to measure, the assumptions as to the signal source should be of a "minimal" nature, i.e., the minimum expected transmitter power and minimum airborne antenna gain. Additionally, it can be expected that the assumptions as to the signal source will be dependent upon the r-f frequency.

Table 2.1-1 is a listing of various types of radiating electronic equipment which might occur as signal sources for the AN/MSQ-16. The transmitted power levels and antenna gains indicated are considered to be minimum expected values.

TABLE 2.1-1

SURVEY OF RADIATING SOURCES

Basic Signal Source	Minimum Xmtr Power	Modulation	Spectrum Width	Minimum Antenna Gain	Typical Frequency Range
Spot Jammer	50 W	Noise	10 Mc	+ 3 db	0.4 KMc - 10 KMc
Swept Jammer	50 W	FM	10 Mc	+ 3 db	0.4 KMc - 10 KMc
Spoofer Jammer	50 W	Pulse	5 Mc	+ 3 db	2.5 KMc - 10 KMc
Communications	5 W	FM/AM	1 Kc - 75 Kc	0 db	100 Mc - 400 Mc
Telemetry	0.1 W	FM	100 Kc - 1 Mc	0 db	0.2 KMc - 3.0 KMc
Radar	10 KW	Pulse	5 Mc	+40 db - 0 db	0.8 KMc - 18 KMc
Radar Beacon	1 KW	Pulse	5 Mc	0 db	1.3 KMc - 10 KMc
Radar Altimeter	0.1 W	FM Pulse	10 Kc - 5 Mc	0 db	2 KMc - 18 KMc
Doppler Navigator	1 W	CW/Pulse	5 Kc - 5 Mc	0 db	5 KMc - 18 KMc

With this data, the required AN/MSQ-16 antenna gains can be computed, once the required signal levels at the AN/MSQ-16 antenna terminals have been determined. For the purposes of these calculations, the required minimum signal level at the AN/MSQ-16 antenna terminals can be assumed to be -90 dbm. This will provide a minimum signal-to-noise ratio of +10 db for wide-bandwidth signals at the high end of the band and a somewhat larger signal-to-noise ratio for narrow-band signals and lower r-f frequencies. The requ.red signal-to-noise ratios for signal intercept and passive tracking are discussed in Sec. 2.4. The one-way line-of-sight range equation can be expressed by the following:

$$P_r = -98 \text{ dbm} + P_t + G_t + G_r + 2\lambda - 2R \qquad (2.1)$$

Where:

P_r = received signal power in dbm at the receiving antenna terminals.

P_t = transmitted power in dbw (db above one watt).

G_t = transmitted antenna gain in the direction of the receiving antenna in db above an isotropic radiator.

G_r = the receiver antenna gain db above an isotropic antenna.

λ = the operating wave length in db over 1 cm.

R = the range between the transmitted and receiver db above 1 nautical mile.

In the case of aircraft equipment, a maximum desired operating range of 50 nm can be assumed. For a minimum value of P_r of -90 dbm the required receiving antenna gain G_r is then given by:

$$G_r = 47 - P_t - G_t - 2\lambda \qquad (2.2)$$

This expression is plotted in Fig. 2.1-1 as a function of r-f frequency (solid lines) for an airborne transmitter antenna gain G_t of 0 db and for transmitter powers P_t of 0.1 and 1.0 watts.

Also shown in Fig. 2.1-1 are the antenna gains and frequency bands considered optimum for the AN/MSQ-16 system. The frequency band selection has been based upon the availability of r-f components, primarily hybrid junctions for passive tracking, and available receivers. With the exception of Band 1, the 0.1 KMc to 1 KMc band, a one-to-one relation can exist between the antennas, r-f system and receivers. The 10:1 frequency range of Band 1 will require at least two and possibly three r-f systems to provide passive tracking across the complete band. This band was not sub-divided on an antenna basis because of the large antenna aperture required and the feasibility of a single antenna to cover this range.

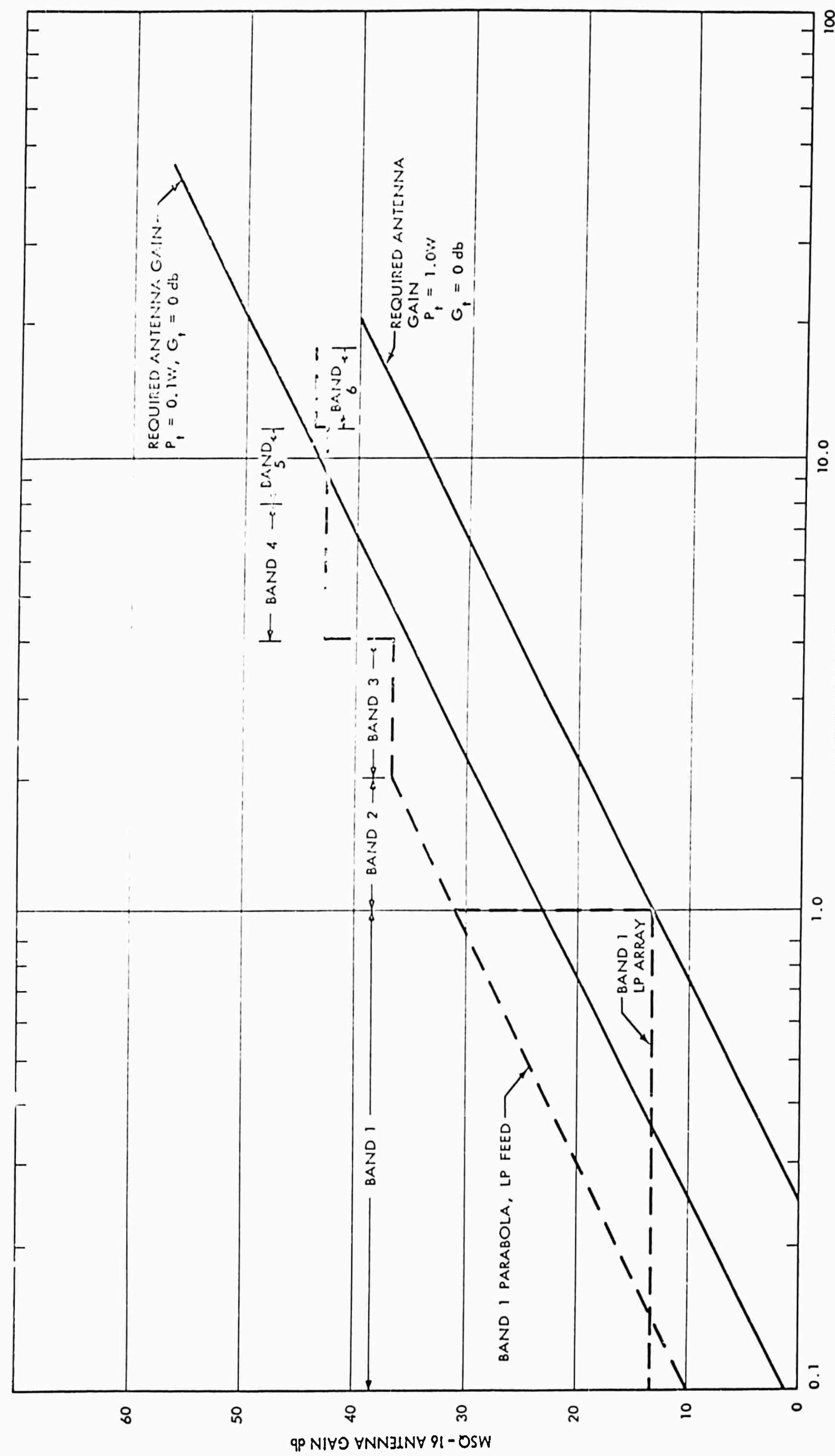


Figure 2.1-1. AN/MSQ-16 Antenna Gain vs Frequency for Various Transmitter Power Levels

It will also be noted that the gain of two possible antenna configurations have been shown for Band 1. The first is a log-periodic array (LP Array) characterized by relatively constant gain and beamwidth for the frequency range of Band 1. The second Band 1 antenna configuration is a parabolic reflector (Parabola, LP Feed) fed by log-periodic feeds. This latter configuration is characterized by constant illumination of the parabolic reflector as a function of r-f frequency, causing the antenna gain to increase as the square of frequency. This latter configuration has the obvious advantage of making full use of the antenna aperture across the full band, providing increased gain at the high end of the band. As will be discussed in the next section, the log-periodic fed parabola has difficulty in providing a dual-polarized quadruple feed for passive tracking, whereas this can conveniently be obtained for the log-periodic array.

In addition to detection and measurement of radiation from aircraft electronic equipment, it is also a system requirement that the AN/MSQ-16 be capable of making measurements of the received signal from possible satellite transmitter sources, primarily, spectrum signature measurements.

In order to compute the expected AN/MSQ-16 performance, various assumptions were made as to the minimum transmitted power and antenna gain of the satellite radiation source. For these calculations, a value of transmitted power of 1.0 and 10 watts was assumed. The transmitter antenna gain was taken as +3 db and the minimum required signal level at the AN/MSQ-16 antenna terminals was assumed to be -90 dbm (S/N = +10 db). These values were substituted into Eq. 2.1, together with the AN/MSQ-16 antenna gains indicated in Fig. 2.1-1 and the maximum range was computed. These results are plotted in Fig. 2.1-2 for the two transmitter power levels. Here, one can see the advantage of the Band 1 parabolic reflector, illuminated by the log-periodic constant-beamwidth feed, i.e., the increase in antenna gain compensates for the λ^2 term in the one-way range equation, providing constant range performance for constant-source conditions.

In addition to the antenna gains, the antenna beamwidths are also of importance, particularly when considering passive tracking and the ground reflection problem.

In the case of a well-designed horn-fed parabolic reflector, the beamwidths can be closely related to the antenna gain, with slight variations as a function of reflector illumination and whether the pattern is in the E or H plane. However, this is not necessarily true for a log-periodic array or parabolic reflector fed by a log-periodic antenna. Table 2.1-2 is a summary of the R-F bands, together with the required antenna gains and estimated beamwidths. It should be noted that since the antennas are dual polarized, the E- and H-plane beamwidths correspond to the azimuth or elevation beamwidth depending upon the choice of vertical or horizontal polarization. The performance of the two approaches to the Band 1 antenna are indicated in the table. The advantages of the parabolic reflector with the LP feed are apparent from a beamwidth standpoint, providing better passive tracking in the frequency range below 1 KMc. This type of antenna is employed for Band 2, as indicated by the increase in gain with frequency. The parabolic reflector with the LP feed becomes quite practical in this frequency range due to the smaller fractional bandwidth and larger relative reflector size compared to the feed size, reducing aperture blocking. These considerations will be discussed in more detail in the following sections.

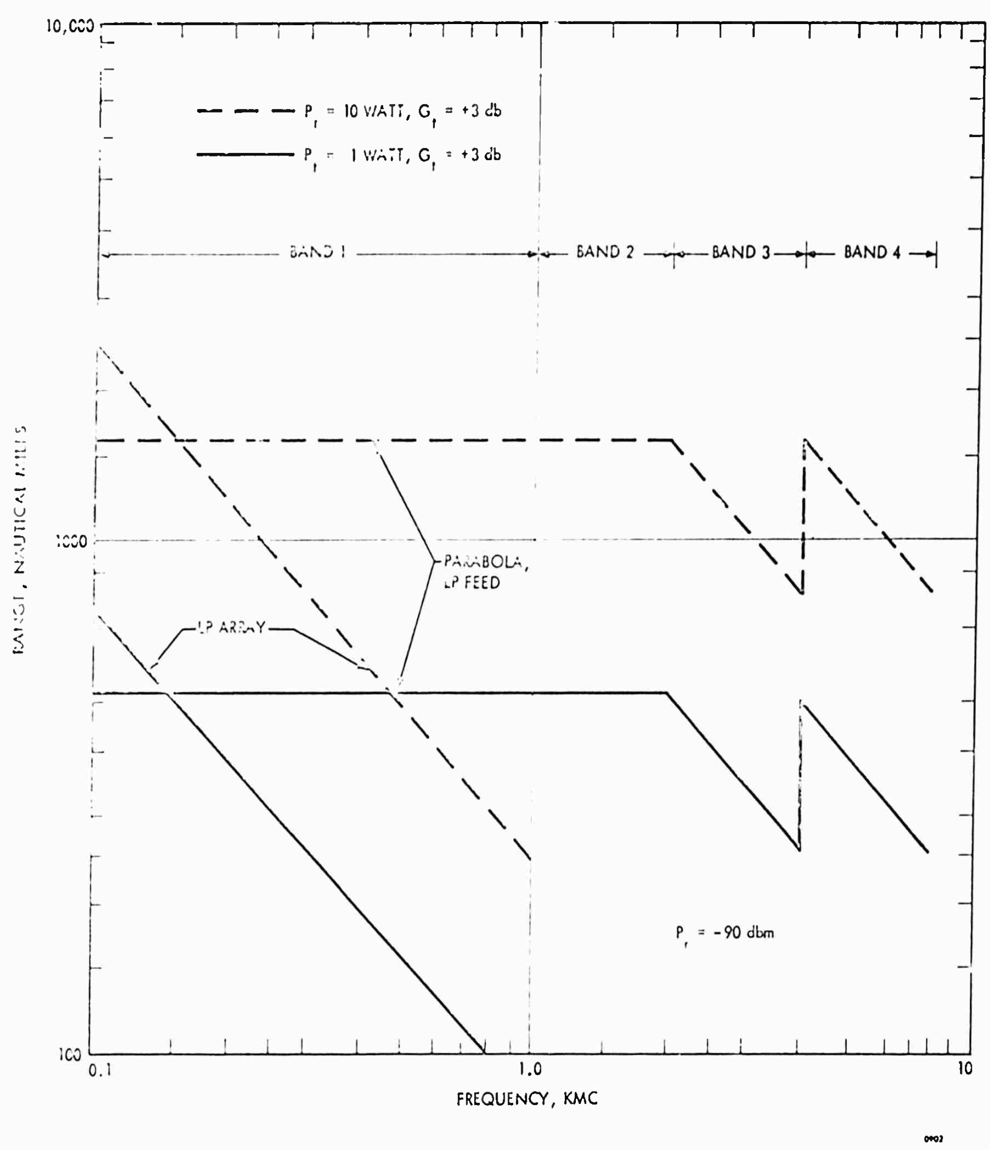


Figure 2.1-2. Expected Satellite Tracking Range vs R-F Frequency

TABLE 2.1-2

SUMMARY OF R-F BANDS AND CORRESPONDING ANTENNA CHARACTERISTICS

Band	Frequency Range	Gain	E-Plane Beamwidth	H-Plane Beamwidth
Band 1 L. P. Array	0.1 KMc 1.0 KMc	13 db	≈45°	≈45°
Band 1 Parabola LP feed	0.1 KMc 1.0 KMc	≈11.5 db 30 db	50° 6°	≈45° 5.5°
Band 2	1.0 KMc 2.0 KMc	30 db 36 db	6° 3°	5.5° 2.7°
Band 3	2.0 KMc 4.0 KMc	36 db	3°	2.7°
Band 4	4.0 KMc 8.0 KMc	42 db	1.5°	1.4°
Band 5	8.0 KMc 12.0 KMc	42 db	1.5°	1.4°
Band 6	12.0 KMc 18.0 KMc	43 db	1.3°	1.2°

2.1.2 Antenna Configurations. - The previous section has determined the required AN/MSQ-16 antenna gains from considerations of the expected signal source, range and AN/MSQ-16 signal level requirements. This section will discuss various antenna configurations, together with their design limitations, to achieve the desired performance.

A class of antennas which has wide application to the AN/MSQ-16 antenna system is the log-periodic antenna. Various types of log-periodic antennas are illustrated in Fig. 2.1-3. This class of antenna is capable of maintaining frequency-independent performance, in terms of input impedance, beamwidth and gain, over a frequency range in excess of 20:1.

The geometry of log-periodic antenna structures is chosen so that the electrical properties of the radiating elements repeat periodically with the logarithm of frequency. Although there are a large variety of log periodic structures that can be employed, the ones shown have proven to be the most practical. The dipole or wire trapezoid type is employed at the lower r-f frequencies and the trapezoidal tooth type at the higher frequencies.

The highest frequency of operation of a log-periodic antenna is approximately equal to the frequency where the shortest element is a quarter-wavelength long, and the lowest frequency is where the longest element is a quarter-wavelength long. Log-periodic antennas have been constructed to operate at a frequency as low as 2 Mc and as high as 8 KMc. However, at frequencies above approximately 5 KMc manufacturing tolerances become severe. The achievable gain of a log-periodic antenna is nominal, being in the region of 7 to 8 db for a single element. However, multiple elements can be arrayed to provide increased gain.

Although a complete theoretical analytical description of the log-periodic antenna is presently unavailable, considerable experimental data is available in the literature (Ref. 1, 2) to provide acceptable antenna designs.

The use of a log-periodic antenna in the AN/MSQ-16 antenna system has major application for the Band 1 (0.1 KMc to 1.0 KMc) antenna, due to the wide frequency range. As indicated in the previous section, the log-periodic antenna may be employed in two configurations. The first is as an array of log-periodic elements, and the second, a log-periodic antenna employed as the feed for a parabolic reflector.

The first configuration is illustrated in Fig. 2.1-4, a & b. Four log-periodic elements are arrayed to provide two elements in the E-plane and two in the H-plane. Each element is of the log-periodic dipole type (Ref. 2) and employs crossed elements to provide vertical and horizontal polarization. The axis of each element is tilted to form a pyramid. The tilt angle is such that the spacing between each element center of radiation is a constant times the wave length, typically 0.7 λ for a good array factor.

Each of the four elements can now be fed separately and combined in appropriate hybrid junctions to provide a sum pattern and a difference pattern in each plane, for passive tracking.

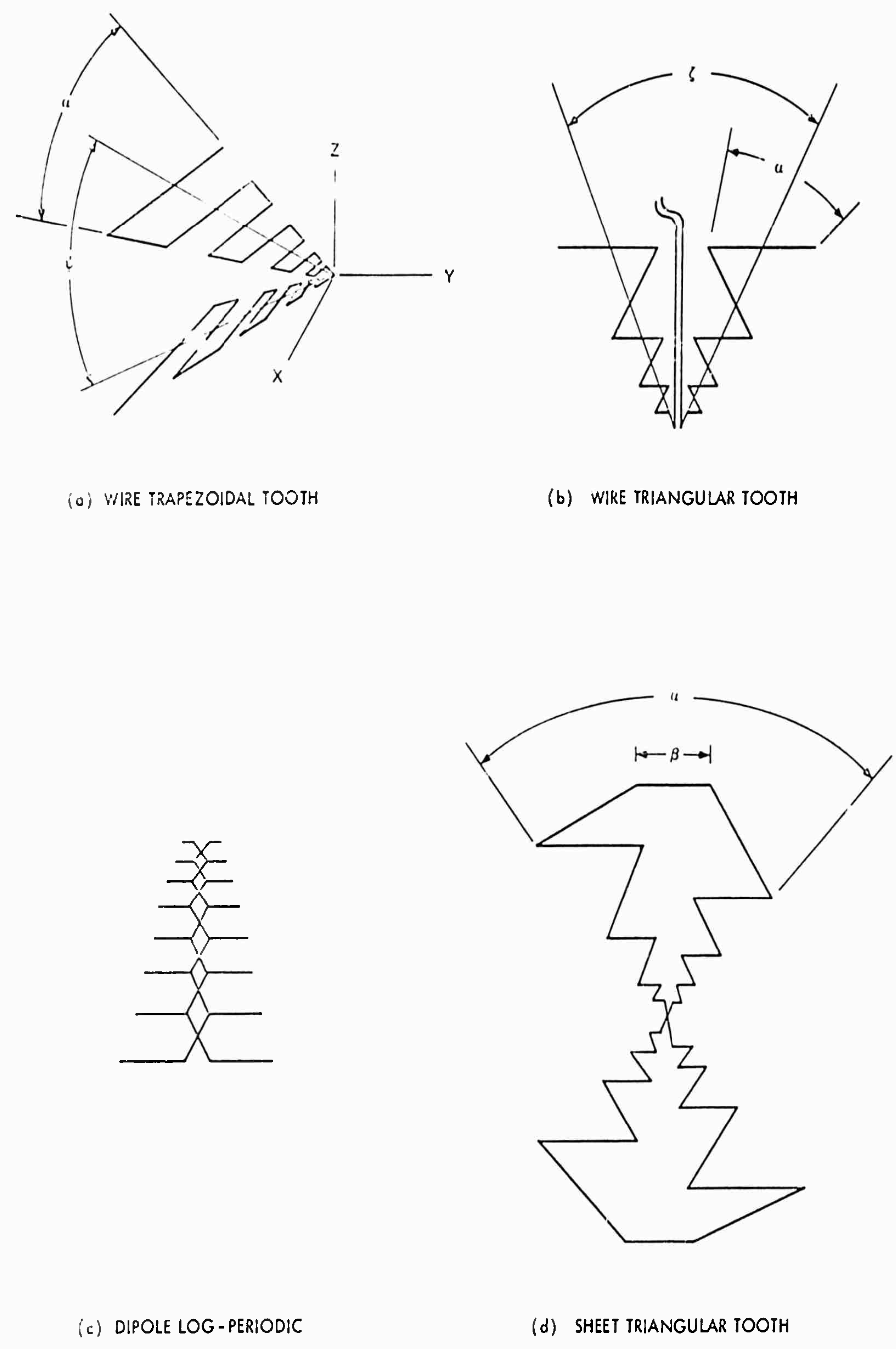
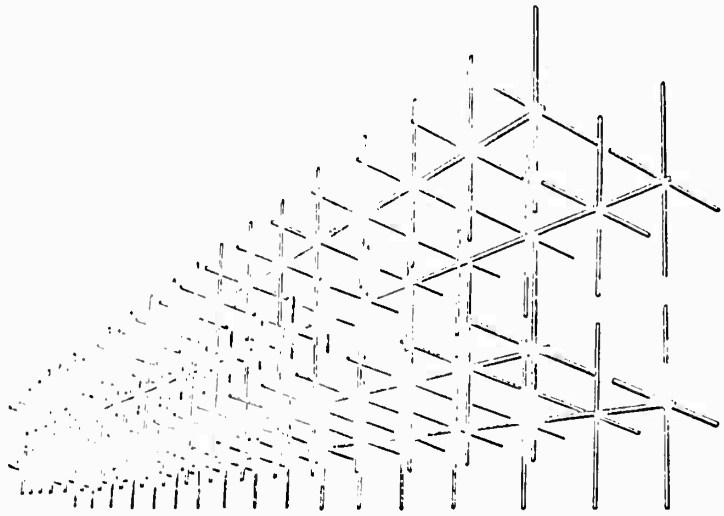
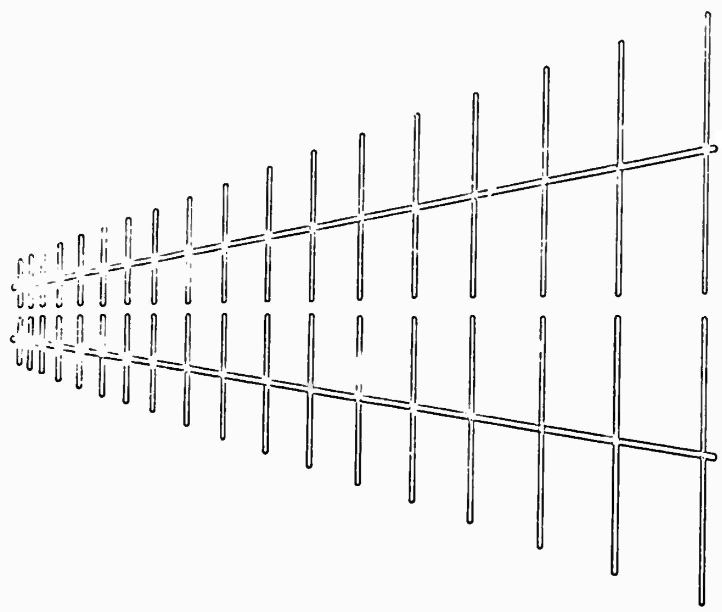


Figure 2.1-3. Several Types of Log-Periodic Antennas



(a) PICTORIAL



(b) TOP OR SIDE VIEW

Figure 2.1-4. Four Half-Element Log-Periodic Array

As previously indicated, this design approach to the Band 1 antenna provides relatively constant sum pattern gain and beamwidth across the band. It has the advantage of being a simpler design and of relatively small size and low wind resistance. Side lobe and back lobes can be held to greater than 20 db below the main lobe gain and the VSWR can be held to less than 1.5:1.

A second approach to the Band 1 antenna, is the use of a parabolic reflector, fed by a multiple element log-periodic array. This approach has the advantage of providing constant reflector illumination as a function frequency, causing the antenna gain to increase with the square of frequency. The disadvantage of this configuration is the difficulty in maintaining the phase center of the log-periodic feed at the focus of the parabolic reflector. The distance from the log-periodic vertex to its phase center or effective point of radiation is directly proportional to wave length, the constant of proportionality being in the region of 0.2 to 0.4.

The effect of de-focusing of the reflector along the feed axis is to cause a quadratic phase error over the reflector aperture. This then results in less gain, a broader beamwidth and higher side lobes. At the present time it is difficult to calculate the effects of feed de-focusing. However, test data is available which will indicate the magnitude of antenna performance degradation due to de-focusing.

Figure 2.1-5 indicates the measured antenna gain as a function of feed location relative to the focal length. This data was taken from an antenna designed to cover the frequency range of 600 Mc to 6 KMc. The dish diameter was 4 feet and the feed consisted of a sheet trapezoidal tooth structure. It will be noted from the data of Fig. 2.1-5 that the high frequency end is quite sensitive to feed location. This is as expected, as feed displacement from the focus, along the feed axis, represents a constant path length difference to the antenna aperture, independent of frequency; however, a path length difference results in a phase error inversely proportional to wave length. As indicated in the figure, for this particular antenna, optimum feed location occurs with the feed vertex located slightly on the reflector side of the focus.

This data indicates quite satisfactory results for the particular antenna, over a 10:1 frequency range. However, it can be expected that with a larger reflector and a higher F/D ratio, the antenna performance degradation with de-focusing will be somewhat worse.

For the AN/MSQ-16 application, the reflector diameter is limited to approximately 18 feet. The log-periodic feed must have a dimension L (See Fig. 2.1-5) of at least 6 feet to operate down to 100 Mc. These approximate dimensions indicate that an antenna designed for the AN/MSQ-16 Band 1 would have less favorable ratios of dimensions than the antenna of Fig. 2.1-5.

It should be noted, that in order to obtain passive tracking, the feed consists of a four-element array, similar to that previously discussed. This should aid the de-focusing problem, as for a given primary pattern beamwidth, the log-periodic elements will be shorter, due to the increase in gain obtained by arraying elements. A detailed design of this antenna is presented in Sec. 4.2.

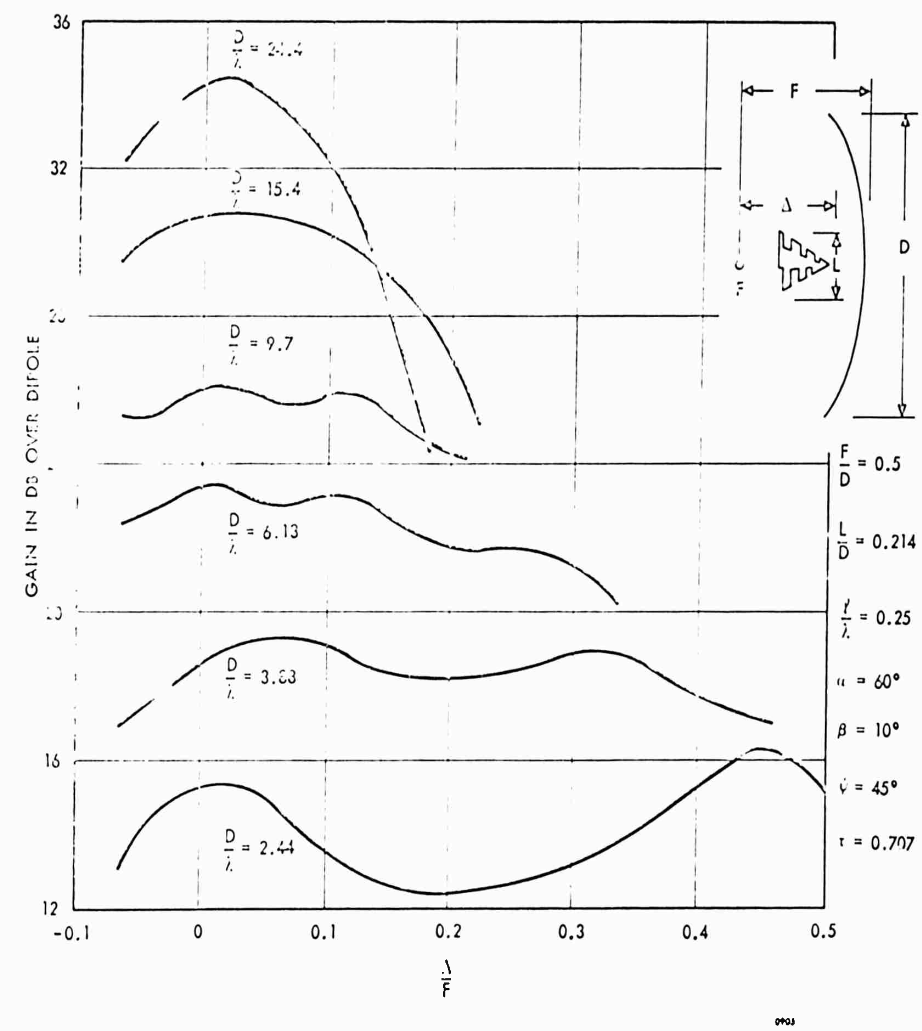


Figure 2.1-5. Antenna Gain vs Feed Position and Frequency, Parabolic Reflector with Log-Periodic Feed

The Band 2 antenna, covering the frequency range of 1.0 KMc to 2.0 KMc lends itself quite well to the log-periodic fed parabolic reflector. Here the de-focusing effect will be much less serious due to the smaller fractional bandwidth and the higher frequencies, allowing a better ratio between feed size and reflector size.

The Band 3 antenna, covering the frequency range of 2.0 KMc to 4.0 KMc, can also employ the log-periodic-fed parabolic reflector. However, consideration has also been given to a possible alternative approach.

The addition of a single or double ridge to conventional waveguide allows the guide to be employed over a bandwidth in excess of 2:1. Ridged wave guide can be employed to excite a pyramidal horn, which in turn can be employed as a feed for a parabolic reflector; four such feeds can then be clustered to provide a passive monopulse tracking capability.

The advantage of this configuration over the log-periodic feed is that dual polarization operation may be more conveniently obtained. This requires that the guide and horn be symmetrical in the E and H planes, with possible reflector illumination problems due to the characteristically different E- and H-plane primary patterns. However, it appears that it may be easier to obtain the desired primary patterns with horns than with the dual polarized log-periodic feeds. One disadvantage of the horn feed is that the antenna gain and beamwidth will tend to remain constant across the band rather than improve as the frequency squared as would be the case with the log-periodic feed. However, since the reflector illumination will improve with increasing frequency (better illumination taper due to a narrower primary pattern), side lobes can be expected to be lower at the upper end of the band, using horn feeds.

The antenna configuration deemed most feasible for Band 4 (4 KMc - 8 KMc), Band 5 (8 KMc - 12 KMc) and Band 6 (12 KMc - 18 KMc) is that using ridged-waveguide horns feeding a parabolic reflector. The manufacturing tolerances of log-periodic feeds become quite difficult as the frequency is increased much above 4 KMc, particularly where dual polarization and passive tracking are required. The reflector dimensions for these higher-frequency bands can be reduced as indicated in the previous sections, to maintain the gain in the region of 42 db. A more detailed description of the antennas is contained in Sec. 4.2.

2.2 PASSIVE TRACKING

Various basic methods exist to provide a passive tracking capability. These are essentially the same techniques employed for active radar tracking, except that instead of transmitting a signal and tracking reflected return, the receiving system tracks a radiating source. Basically, the receiving system for passive tracking can be similar to those employed for active or radar tracking. The major differences are that (1) no range tracking is possible and (2) the passive tracker is required to identify the r-f frequency before angle tracking can be initiated. In addition, (3) passive tracking is usually required to operate over wide r-f bandwidths.

Three basic types of tracking systems can be considered for the AN/MSQ-16. These are sequential lobing, r-f comparison monopulse, and video-comparison monopulse. Of these three tracking methods, sequential lobing is the simplest, in respect to both the antenna and receiver design. The principal characteristic of a sequential lobing system is that directional information is obtained by comparing samples of the received signal amplitude as the antenna beam angle is moved about the signal direction angle. This is normally accomplished by rapidly switching between alternative beam positions or by conical scanning a squinted beam around the boresite axis. In sequential lobing there is inherent some time difference between signal samples. If the beam is conically scanned by mechanical means (the most-used technique), the time between samples of opposite error polarity is one half the period of a single complete conical scan cycle, or 1/60 second for 30 cps scan rate. If within this time interval, the incident signal level changes, significant angle-tracking errors can be introduced. It is for this reason that a sequential-lobing or conical-scanning system is not employed for the tracking of signals which can exhibit rapid changes in amplitude. It can be expected that the AN/MSQ-16 will be required to track such signals.

In addition, rapid mechanical movement of the low-frequency AN/MSQ-16 antenna feeds does not appear feasible. Beam switching between multiple beam positions is, at least as far as antenna design is concerned, as complicated as a monopulse system, with the disadvantage of being susceptible to tracking errors introduced by rapid signal fluctuations. For these reasons, a simultaneous-lobing or monopulse tracking system is required for the AN/MSQ-16 rather than a sequential-lobing system.

In the monopulse system, directional error information is obtained essentially instantaneously by simultaneous comparison of opposed lobes, so that signal-amplitude variations as a function of time cannot affect the tracking accuracy.

Two basic types of monopulse tracking systems can be considered for use in the AN/MSQ-16; r-f comparison monopulse and video-comparison monopulse. The antenna requirements for either type are essentially the same; however, the receiving systems are quite different.

Figure 2.2-1 is a basic block diagram of an r-f comparison monopulse tracking system. This is a so-called r-f amplitude-comparison system as opposed to a phase-comparison system. A phase-comparison monopulse tracker is not considered for the AN/MSQ-16 due to the difficulty of obtaining satisfactory operation over a wide range of r-f frequencies. Phase information is preserved in the r-f amplitude-comparison system; however, this information is employed only to determine the sense of the tracking error rather than error amplitude.

Figure 2.2-2 indicates typical antenna patterns for the sum channel and for either the elevation- or azimuth-difference channel. Ideally, the four antenna feeds are located at the reflector focus and squinted slightly off the sum-channel axis, two in the azimuth plane and two in the elevation plane. However, since all four feeds cannot be located at the focus, the feed assembly is normally designed so that the reflector illumination is near optimum for the sum channel (all four feeds fed in phase). The fact that the individual feeds are off the focus and do not illuminate the reflector

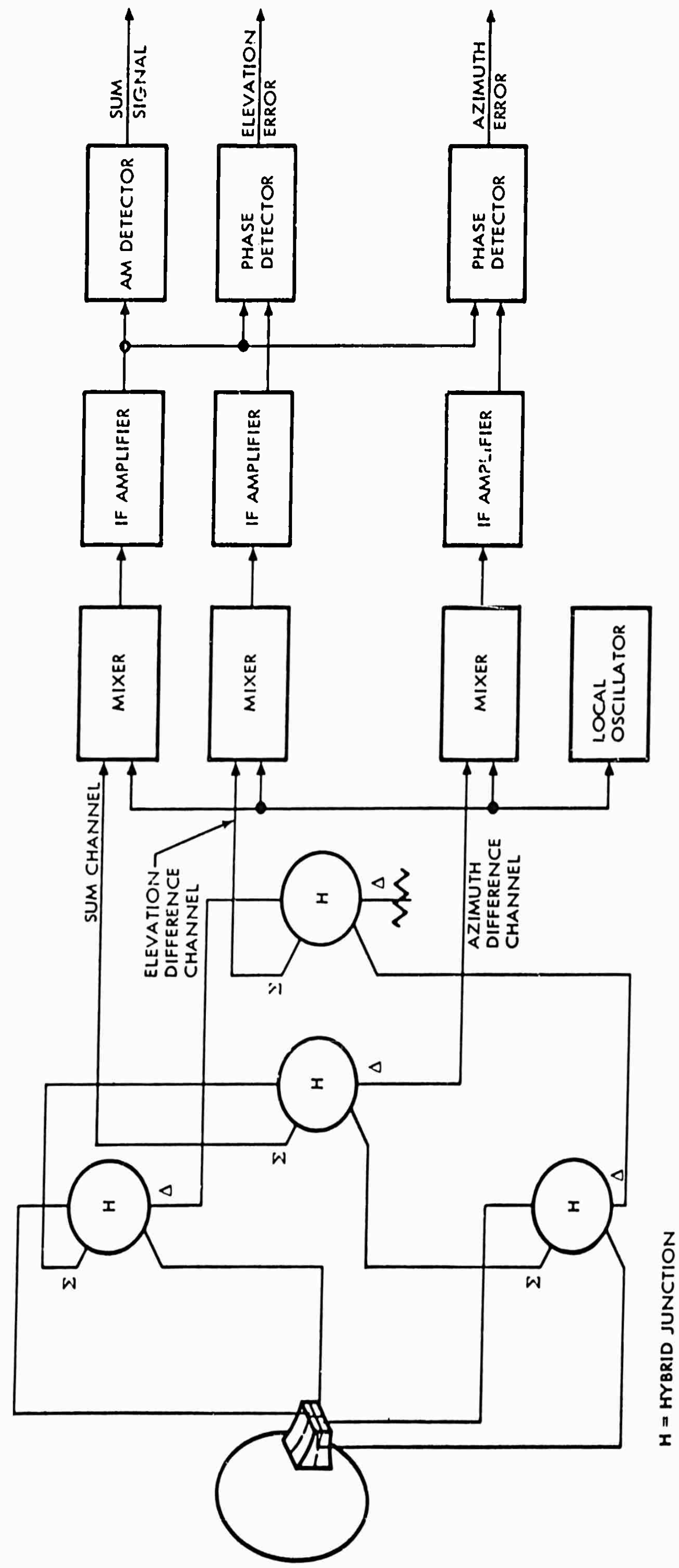


Figure 2.2-1. Block Diagram, R-F Amplitude Monopulse Passive Tracker

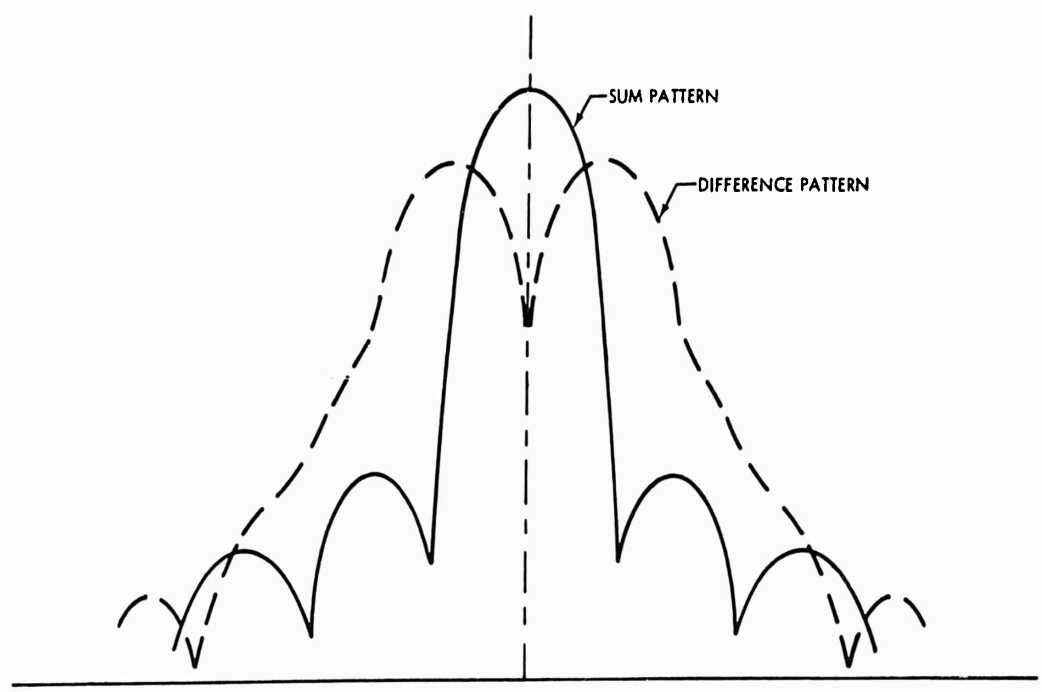


Figure 2.2-2. Typical Monopulse Sum and Difference Attenna Pattern

optiminally, accounts for the higher side lobes in the difference pattern of Fig. 2.2-2. More complex feed arrangements (Ref. 3) are available to provide independent optimization of the sum and difference reflector illumination; however, these are considered far too complex for a wide-band system such as the AN/MSQ-16.

The principal design problem of the r-f comparison monopulse passive tracker, as it relates to the AN/MSQ-16, is that of obtaining the desired performance of the r-f system over the required r-f frequency range. The most critical requirement is signal-amplitude balance between the four feeds prior to r-f differencing within the hybrids. Signal-amplitude unbalances will cause a direct boresite shift and a resulting tracking error.

Figure 2.2-3 indicates the angular tracking error as a ratio of error to beamwidth (θ_S/ϵ) as a function of amplitude unbalance, for various ratios of beam separation to beamwidth (ψ/ϵ). This and subsequent data was obtained from Ref. 6.

It should be noted that the signal-amplitude unbalance includes antenna gain unbalances between each feed, transmission line unbalances and unbalances within the hybrids themselves. Additionally, the term unbalance refers to changes that might occur after collimation, principally, in the case of the AN/MSQ-16, due to a major change in r-f frequency from the collimation frequency.

Although not as critical as pre-difference amplitude errors, pre-difference phase errors also deteriorate the tracking performance of a passive tracker. The major effect of phase unbalances prior to r-f differencing is to cause the depth of the difference-pattern null to increase. This is the same as reducing the slope of the phase detector output in terms of volts/degree off bore site and has the effect of reducing ψ/ϵ, making the system more sensitive to pre-comparison amplitude unbalances and to various system noises. Figure 2.2-4 indicates the antenna difference-pattern null depth as a function of pre-comparison phase difference for various values of ψ/ϵ.

In addition to pre-comparison phase differentials, phase differences between the sum channel and the difference channels may exist, i.e., post-comparison phase shifts. Post-comparison phase shifts have the effect of reducing the crossover slope, and if they exist in addition to pre-comparison phase shifts, will cause a second-order bore-site shift. This effect is illustrated in Fig. 2.2-5, which is a plot of bore-site shift as a function of post-comparison phase shift for a particular antenna beamwidth ($\epsilon = 5°$) and pre-comparison phase shift ($\alpha = 5°$) for various values of ψ/ϵ. It should be noted from the various error data presented, that for a given system unbalance, the resulting tracking error is minimized by a high beam separation or squint-to-beamwidth ratio (ψ/ϵ). This data is based upon an assumed antenna voltage pattern which is proportional to the sine of the angle from maximum radiation. In the case of more realistic patterns, there is an optimum ratio of squint angle to beamwidth which will maximize the crossover slope and minimize the effects of system unbalances. Depending upon the particular pattern, maximum slope occurs in the region of ψ/ϵ between 0.6 and 1.0, corresponding to beam crossover at the -1.2 to -3 db points.

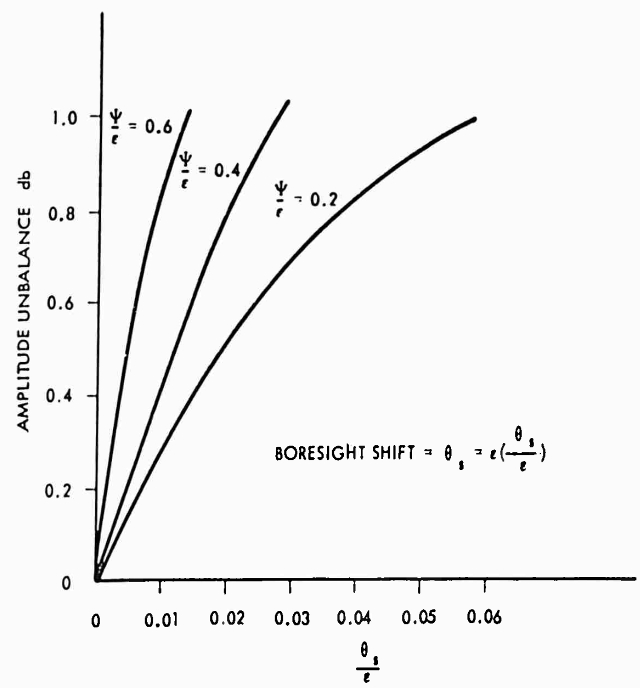


Figure 2.2-3. Boresight Shift vs Pre-Comparator Amplitude Unbalance

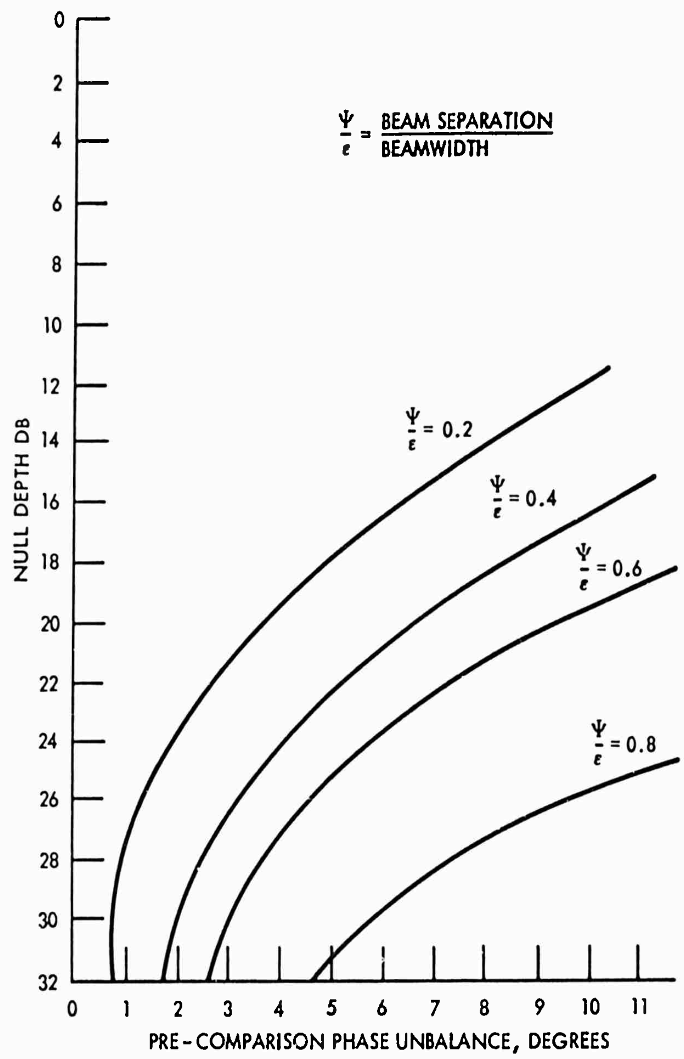


Figure 2.2-4. Antenna Difference Pattern Null Depth vs Pre-Comparison Phase Unbalance

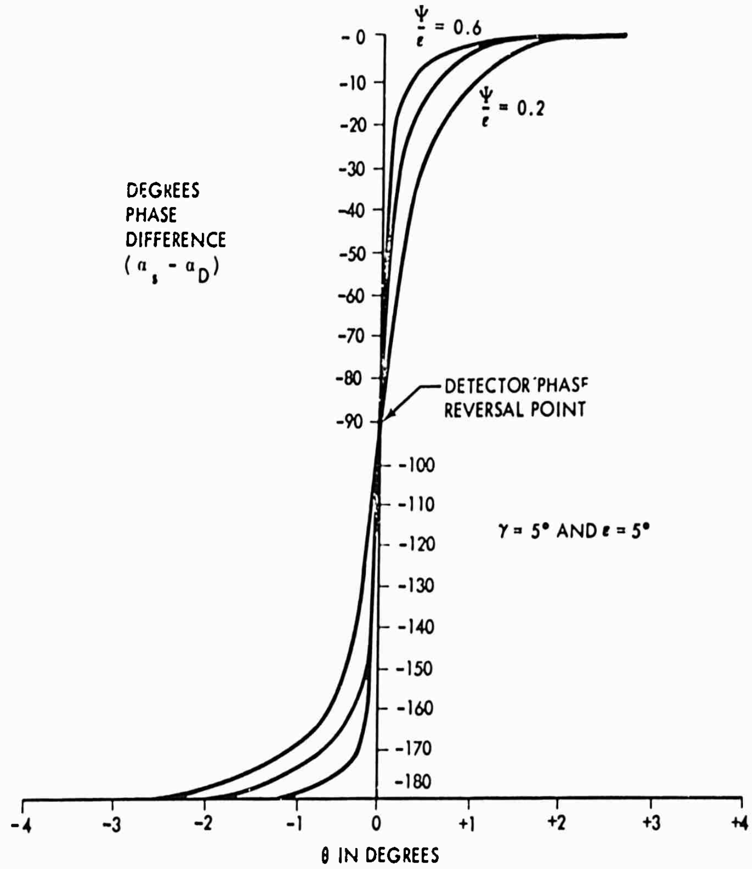


Figure 2.2-5. Phase Difference between Sum and Difference Channels vs Target Angle Relative to Boresight

The second type of monopulse passive tracker that may be considered for the AN/MSQ-16 is the video-comparison tracker. This tracker has the same antenna configuration as the r-f comparison tracker; however, in the video-comparison tracker, differencing is accomplished after detection of the received signal. Figure 2.2-6 is a block diagram of the video-comparison system. The principal advantage of this arrangement is that the r-f portion of the system is relatively independent of frequency and the r-f tuning range is limited only by the antenna beamwidth and the tuning range of a conventional receiver. However, the video-comparison system has some disadvantages, the principal one being its sensitivity to gain unbalances between channels. Gain balance is somewhat difficult to control to the required accuracy since in this system gain balance is required for all the elements in the entire receiver chain. Additionally, since overload cannot be tolerated, an AGC system must be employed and applied in such a manner as to avoid introducing gain unbalances as a function of signal level.

The tracking error caused by gain unbalance in the video-comparison scheme is similar to that caused by pre-comparison unbalances in the r-f comparison system. Reference to Fig. 2.2-3 indicates that the gain balance should be on the order of 1 db to maintain the tracking error to less than 2% of a beamwidth. On the other hand, phase errors are of no consequence in the video-comparison system.

The problem of maintaining gain balance between the various receiver channels has been solved by the use of a pilot signal. The pilot signal is an r-f pulse signal which is injected at equal level into each channel. After detection and differencing, the residual pilot signal is selectively gated and employed to adjust the receiver channel gains for cancellation of the pilot pulse, thus achieving balance. The problem of applying AGC has been solved by employing a different i-f frequency in each channel. The channels are then mixed and amplified through a common amplifier which has a band pass wide enough to accept all channels. The AGC signal, developed from the sum signal, can now be employed to control the gain of the common amplifier to provide a constant sum-signal output, independent of the r-f signal input. Since all channels are amplified by the same common amplifier, no gain unbalance will be introduced by the AGC circuit, and channels can be separated at the amplifier output on the basis of their i-f frequency.

A video-comparison monopulse system, as just described, was constructed and employed in the passive tracking system of the AN/MLQ-7 countermeasures equipment. This equipment provided passive tracking over a 4 KMc tuning range at X-band, with an angle tracking accuracy of 1 milliradian.

The choice between which type of tracker should be employed in the AN/MSQ-16 is dependent upon the performance of the r-f components available for the r-f comparison system. The r-f comparison system is less complex than the video-comparison system, so that if it can be designed to cover the required tuning ranges it would be the logical choice.

The r-f component that imposes the greatest tendency to limit the tuning range of the r-f comparison system is the hybrid junction, particularly in regard to amplitude balance vs. frequency. However, recent developments indicate (Ref. 7) that balance can be maintained within ±0.4 db over a 5:1

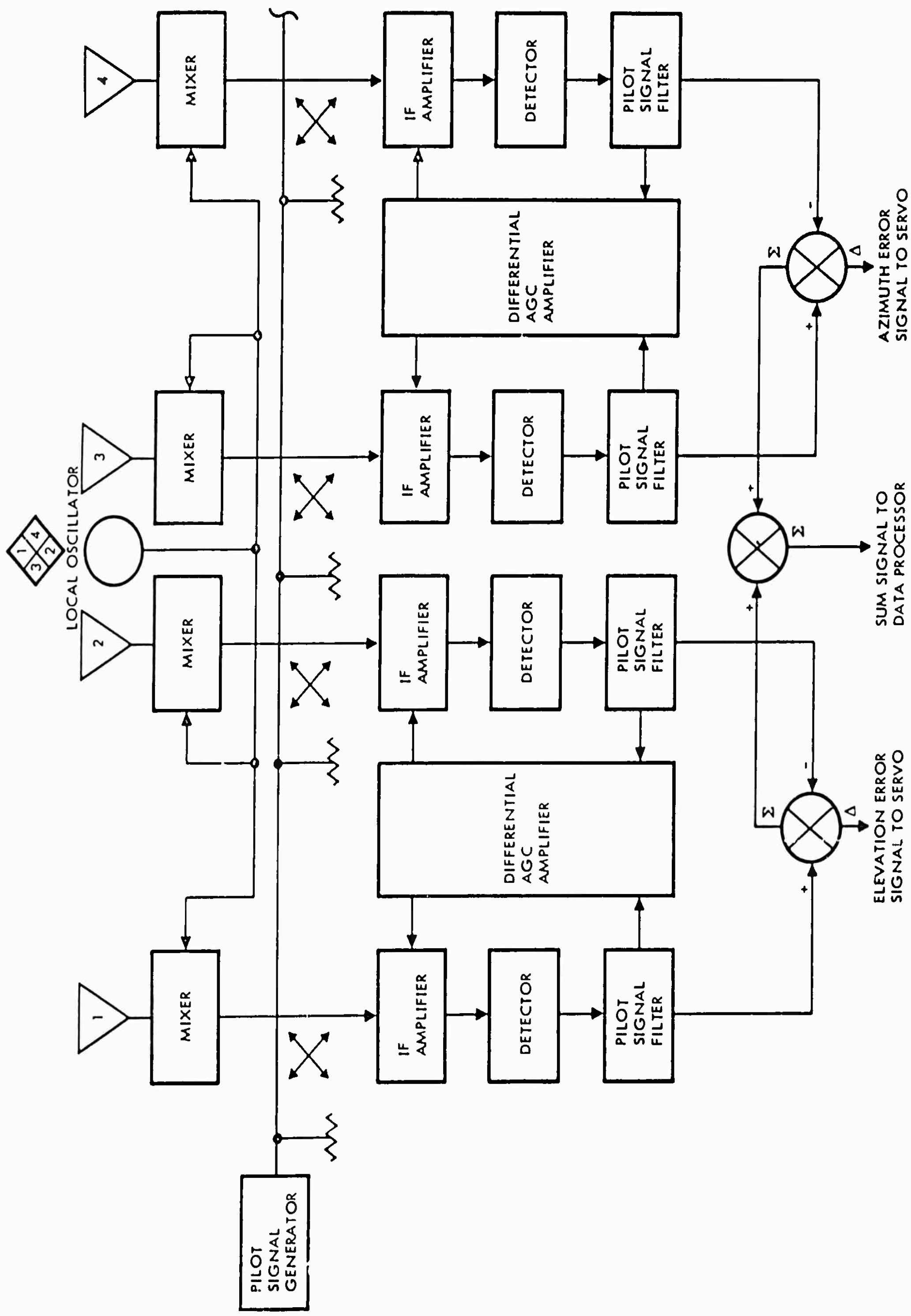


Figure 2.2-6. Block Diagram of Basic Video Comparison Monopulse Tracking System

bandwidth. These hybrids have been designed to operate at frequencies up to 5 KMc and it is believed that this can be extended to X-band. This potentiality points to the use of an r-f comparison monopulse tracking system for the AN/MSQ-16. Although a single r-f configuration will not cover the complete Band 1 (0.1 KMc to 1.0 KMc), three separate designs can be employed to obtain the necessary tuning range. A more detailed discussion of the passive tracking receiver is contained in Sec. 4.4.

2.3 SIGNAL DISTRIBUTION AND TRANSMISSION

As indicated in the previous section, the use of r-f differencing monopulse tracking can be employed to provide a passive tracking capability for the AN/MSQ-16. Due to the tight tolerances required for pre-differencing amplitude and phase balance, the hybrid junctions, necessary to provide the two difference- and sum-channel signals, must be located as close to the antenna feeds as possible.

In addition, in order to make full use of the available antenna aperture the sum signal from the hybrid output should be employed for signal-level measurements. This requires that two sets of hybrids be employed, one for horizontal polarization and one for vertical polarization, in order to provide the capability of simultaneous monitoring of both polarizations.

As previously indicated, at least an additional two sets of hybrids will be required for Band 1, as hybrids are presently unavailable to cover the required 10:1 bandwidth. However, as discussed in the next section, it appears advisable to divide the Band 1 into 3 sub-bands in order to be compatible with available pre-amplifiers and receivers and avoid even more complicated band switching.

In addition to the various signal channels from the antennas, calibration signals are also required. In order to obtain as accurate an amplitude calibration of the sum-signal channels as possible, it is desirable that the calibration signals be injected as close to the antennas as possible. This further complicates the signal-transmission problem.

Table 2.3-1 is a tabulation of the various r-f signal channels that exist at the antenna mount for the various frequency bands. Since passive tracking can only be employed to track a particular frequency and polarization, only two of the difference-channel signals are employed at one time. Additionally, as discussed in the next section, the azimuth and elevation difference channels can be time shared without loss of the monopulse tracking features. This further reduces the number of difference channels required to be transmitted to the receiver to a single channel. However, since this channel could be at any r-f frequency within the total band, at least 8 such channels would be required, assuming that the channels are not frequency multiplexed. Frequency multiplexing could be employed, particularly at the lower frequencies to reduce the number of channels still further. However, the reduction does not appear significant. The number of channels in simultaneous use is still too large to permit the use of rotating joints to transmit separate channel signals through a common azimuth axis.

TABLE 2.3-1

SUMMARY OF SIGNAL TRANSMISSION CHANNELS

Band	Freq. Range	Sum Channels	Difference Channels	Calibration Signals
Band 1	0.1 KMc - 1 KMc	6	12	3
Band 2	1 KMc - 2 KMc	2	4	1
Band 3	2 KMc - 4 KMc	2	4	1
Band 4	4 KMc - 8 KMc	2	4	1
Band 5	8 KMc - 12 KMc	2	4	1
Band 6	12 KMc - 18 KMc	2	4	1
	Total Channels	16	32	8
	Total Channels in Simultaneous Use	16	8	8

Additional considerations, particularly signal attenuation and unbalanced phase shifts, indicate that the receiver pre-amplifiers, tuner assemblies and calibration generators must be located with the antennas. It is estimated that the path length between the antenna assembly and main equipment location could be made as short as 125 feet, and desirably longer. Waveguide attenuation at the higher frequencies would be at least 6 db and probably higher due to the requirement for some flexible sections and a number of joints. Additional problems such as moisture condensation, would require special attention.

Phase matching between the sum and difference channels would also be a problem. As indicated in Sec. 2.2 phase shifts after r-f differencing are not highly critical; however, in order to prevent second order bore-site shifts and loss in cross-over slope, these phase unbalances should be kept to less than 15 to 20 degrees, which includes phase unbalances within the receiver channels themselves. This degree of phase balance between long transmission lines appears difficult to achieve.

The location of a large amount of electronic equipment within the antenna mount has the obvious disadvantage of less equipment accessibility, an increase in equipment complexity in order to obtain complete remote operation, additional mount weight, and difficulty in providing protection from severe environments. However, these disadvantages can be overcome by good equipment design.

The location of the front-end portions of the receivers within the antenna mount will provide maximum receiver sensitivity. Additionally, signal transmission to the main equipment location can now be made at i-f frequencies, simplifying the signal transmission problem. The use of rotating joints at i-f can now be considered practical, eliminating the requirements for a cable wind-up system. For these reasons, it is concluded that the complete r-f system, including pre-amplifiers, receiver tuning heads and calibration generators should be located with the antennas on the antenna pedestal.

2.4 RECEIVERS

The major problems in AN/MSQ-16 receiver design are those of extreme width of frequency coverage and image rejection. All of the requirements of RADC-5111 are readily satisfied on a narrow-band basis; however, AN/MSQ-16 provides six bands for continuous coverage from 0.1 to 18 Gcs, defined as follows:

BAND	Gcs
1	0.1 - 1.0
2	1 - 2
3	2 - 4
4	4 - 8
5	8 - 12
6	12 - 18

Both full-band sweep and variable-sector-width sweep are to be provided. On the basis of information derived from surveying the band, any particular signal may be selected for special attention. The receiver function for that signal would then change to fixed-frequency reception, and the content of the information fed to the Data Processor would be frequency and amplitude. An auxiliary and concurrent receiver function must also be safisfied, namely the derivation of servo control signals to direct the antenna array in the passive tracking mode.

This section discusses the ways in which the usual receiver parameters may be optimized with regard to the above requirements.

2.4.1 Sensitivity. - In a receiving system of the type required for the AN/MSQ-16, it is obviously desirable to obtain as high a receiver sensitivity as possible, within limits imposed by cost and complexity. The principal elements which will determine the receiver sensitivity are any losses that occur before appreciable gain and the noise figures of the low level stages.

The signal level required for a unity signal-to-noise ratio at the input to the receiver detector may be expressed by the following relation:

$$S_{min} = N.F._R \times KT\,\Delta F$$

where:

S_{min} = signal level referred to the receiver input for S/N = 1

$N.F._R$ = the overall receiver noise figure

K = Boltzmann's Constant

T = absolute temperature, deg K

ΔF = the i-f bandwidth

This equation can be expressed in db values at T = +293°K as

$$S_{min}\,(\text{dbm}) = N.F._R\,(\text{db}) - 114\ \text{dbm} + 10 \log \Delta F/1\ \text{mc}.$$

The overall receiver noise figure, $N.F._R$ is primarily determined by the receiver input configuration. Table 2.4-1 indicates a summary of noise figures for various input configurations, i.e., traveling wave amplifier (TWT), tunnel diode amplifier (TD) and a diode mixer. The noise figures indicated in the table are for an r-f bandwidth equal to the complete frequency coverage of the bands indicated. The TWT and tunnel diode noise figures are for the amplifiers alone; however, the diode mixer noise figure assumes that the mixer is followed by an i-f amplifier with a 1.5 db noise figure.

TABLE 2.4-1

NOISE FIGURES VS FREQUENCY

Band	Frequency	TWT N. F.	TD N. F.	Diode Mixer N. F.
1a	100 Mc - 250 Mc	—	3.5 db	6.5 db
1b	250 Mc - 500 Mc	3.5 db	3.5 db	6.5 db
1c	500 Mc - 1000 Mc	4.5 db	5.0 db	6.5 db
2	1.0 KMc - 2.0 KMc	4.5 db	—	7 db
3	2.0 KMc - 4.0 KMc	5.0 db	—	7 db
4	4.0 KMc - 8.0 KMc	5.5 db	—	7.5 db
5	8.0 KMc - 12.0 KMc	7.5 db	—	7.5 db
6	12.0 KMc - 18 KMc	9.0 db	—	8 db

Other input devices could be considered, such as a parametric amplifier. However, the AN/MSQ-16 requires image rejection, and is required to be capable of rapid frequency scanning. The present state of parametric amplifier development can provide instantaneous bandwidths of approximately 3%, so that a parametric amplifier would have to be rapidly tunable. A panoramic amplifier with a 1.5 db noise figure has been developed by Loral Electronics (Ref. 36) which can be tuned over the band of 200 Mc to 800 Mc by sweeping the pump frequency. However, it is anticipated that considerable development would be required to scale this performance to higher r-f frequencies.

An examination of Table 2.4-1 indicates that tunnel diode amplifiers can provide octive bandwidths through the Band 1 frequency range. The low frequency end of Band 1 (Band 1 a) could employ a vacuum tube amplifier with a noise-figure comparable to the tunnel diode amplifier; however, the high reliability of the tunnel diode amplifier makes it more desirable for this application. Throughout the remaining bands, TWT amplifiers appear to offer the best choice. The overall receiver noise figure can be obtained from the basic relationship for the cascading of noise-figures, i.e.;

$$F_{o.v.} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \cdot G_2} + \ldots$$

where G_1, G_2, etc., are the available power gains of the devices with their respective noise figures. In the case of the AN/MSQ-16, the wide band pre-amplifiers should be followed by the pre-selector and/or image rejection circuitry. This prevents deterioration of the overall receiver noise figure by 3 db, since the wide band amplifier produces noise at both the signal and image frequencies. In addition, the pre-selector insertion loss merely reduces the amplifier gain, rather than adding directly to the overall receiver noise figure as would occur if the pre-selector was ahead of the amplifier. The main advantage to this latter configuration is that r-f bandwidth narrowing is obtained ahead of amplification, preventing a high level off-frequency signal which limits in the amplifier from suppressing a signal within the pre-selector pass-band. However, the improvement in receiver sensitivity warrants the use of pre-amplification ahead of pre-selection.

Table 2.4-2 summarizes the calculated overall receiver noise-figures and expected receiver sensitivity for the various bands. These calculations assumed a 2 db pre-selector loss following the r-f pre-amplifier, and a broad-band crystal mixer following the pre-selector. An additional 2 db loss ahead of the r-f pre-amplifier has been included (added directly to the overall receiver noise figure) to include the effects of r-f losses ahead of the pre-amplifier. This loss is increased to 4 db for Band 1, due to the requirement for a band separation filter.

As indicated in Sec. 2.1, the calculation of the required antenna gains was based on the requirement that with the assumed signal sources and range, a -90 dbm signal level is required at the antenna terminals to give at least a 10 db signal to noise ratio at the receiver output. It can be seen from Table 2.4-2 that this requirement is exceeded at all frequencies and the performance calculations are conservative.

TABLE 2.4-2

CALCULATED RECEIVER NOISE FIGURE AND SENSITIVITY

Band	R-F Pre-Ampl. N.F.	R-F Pre-Ampl. Gain	Overall Rcvr Noise Figure	Receiver Sensitivity S/N = 1, ΔF = 1.5 Mc
1a	3.5 db	15 db	3.9 db	-104.7 dbm
1b	3.5 db	15 db	3.9 db	-104.7 dbm
1c	5.0 db	15 db	5.2 db	-103.0 dbm
2	4.5 db	28 db	4.56 db	-105.6 dbm
3	5.0 db	28 db	5.06 db	-105.1 dbm
4	5.5 db	28 db	5.54 db	-105.7 dbm
5	7.5 db	28 db	7.52 db	-103.7 dbm
6	9.0 db	28 db	9.01 db	-101.0 dbm

The tangential receiver sensitivity for an AM pulsed signal, as viewed on an A scope, can be obtained by lowering the S/N = 1 sensitivities by 7 db. This gives tangential sensitivities outside the specification limit of -100 dbm; however, it is felt that the values given are the best obtainable without a large increase in complexity and development effort.

2.4.2 Preselection. - The preselection function in widely tunable receivers is generally one of the most difficult to implement. The preselector must be capable of rapid tuning and must track the receiver local oscillator. The dynamic range of this receiver is specified as 60 db minimum. With a maximum input signal, any spurious response should not be detectable, i.e., it should not exceed the noise level. Thus, the rejection factor for the image (a spurious signal) should be at least 60 db and preferably greater.

For panoramic and sector sweeping, a maximum image rejection is not necessary; at times it is not even desirable. For example, weak-signal detectability is actually enhanced if the image is presented. But image rejection does become a problem in fixed-frequency operation. If the first intermediate frequency is high enough for the image rejection to be accomplished by the selectivity skirt of the pre-amplifier, there is no need for a separate pre-selector filter. This calls for the i-f center frequency to be located several preamp bandwidths away from the preamp band edge. Since several preamps are to have octave bandwidths, the necessary upconversion becomes increasingly difficult for all but the three subdivisions of Band 1. Until recently the only possible pre-selector was the multi-section cavity, mechanically linked for appropriate individual cavity tracking. The tuning rate is necessarily slow, hundreds of milliseconds from limit to limit. The maximum number of cycles is dependent on mechanical wear. While this device is not suitable for the Pan and Sector sweep modes, its use in the fixed-frequency mode is practical and could be facilitated by a servo drive controlled by the first L.O. frequency. Moreover, the device provides minimum insertion loss. Within the past couple of years, garnet ferrite technology has progressed to such a degree that there are now available electronically-tuned bandpass filters covering Bands 2 through 6 with reasonable insertion losses (on the order of 2 db) and usable skirt selectivity (45 db to 50 db maximum rejection). Some problems still exist with YIG filters in random spurious responses and tuning hysteresis but these can probably be reduced to a tolerable level with development.

Some 30 db of image rejection is achieved by the use of octave bandwidth hybrid mixers to provide suppression of the unwanted sideband, with deterioration to 20 db at the band edges. This, together with the YIG filters, can provide the required overall rejection of 60 db minimum.

MELABS, Inc., claims a dynamic rejection capability of 60 db or better for their microwave panoramic receivers in the sweeping mode only, employing sideband suppression mixers with a form of video cancellation. In the fixed-frequency mode, rejection falls to the expected range of 30 to 20 db.

VITRO LABORATORIES (Ref. 34) describes a sequential receiver system using a multiple conversion scheme with the spectrum divided down to 1-Gcs segments. These 1-Gcs bands are further divided into 10 subsegments of 100 Mcs each, any five of which are available for simultaneous inspection. The specifications indicate a 70-db image- and spurious-rejection goal.

2.4.3 AGC and IAGC. - With maximum linear detector dynamic range being typically less than 20 db, the system dynamic range requirement of 60 db necessitates a form of signal compression. This can be accomplished in either of two ways; by AGC with a suitable response time, or by a logarithmic predetection amplifier. The use of AGC requires special consideration of signal characteristics with the necessary choice of time constants and signal weighting. The AGC level can be used to good advantage as an indication of absolute received signal strength, with an accuracy on the order of 2 to 3 db for CW signals.

The use of a logarithmic i-f amplifier, on the other hand, is free of these variables but this technique has inherently a much higher order of complexity, requiring considerably more maintenance.

The presence of an interfering pulse signal can be largely overcome by the use of IAGC, or instantaneous automatic gain control ahead of the normal AGC loop. The technique may take the form of one or more very fast rise and decay auxiliary gain-compression loops around two or three stages each, adjustable for virtual blanking of the interfering pulse signal when the desired signal is of a non-pulsed nature. In this case, the receiver bandwidth following the IAGC function can be made small enough so as not to "see" the very short spike which gets through during IAGC rise time. This technique is most suitable for preventing pulses from capturing a normal AGC loop and thus suppressing receiver sensitivity when working with a continuous signal.

2.4.4 Frequency Scanning. - This function may be approached in two ways. In one method, the receiver first L. O., is swept over the range of interest, with the following i-f stages operating at fixed frequency. For the AN/MSQ-16, Band 1 covers a decade and remaining bands are of octave or near-octave widths. Electronic sweeping over such wide ranges can be done most easily with BWO's (Backward-Wave oscillators). Klystrons could be used, but would impose a need for mechanical tuning in addition to electrical tuning to cover the full width of each band. The only advantage of klystrons over BWO's is a lower possible residual frequency modulation of the L. O. from extraneous noise and fields, which is important to fixed-frequency, narrow-band operation. The alternative to sweeping the first L. O. is to employ double conversion, and to sweep the second L. O. The r-f band can be subdivided down to several overlapping bands of constant width (say, 100 Mcs) each of which is scanned, either simultaneously in groups, sequentially in series, or sequentially in simultaneous groups. This scheme has several very attractive advantages: The image-rejection problem can be solved without the use of scanning preselectors; the various first L. O.'s can all be crystal-controled; frequency scanning can be on a staircase basis, with the increment determined by the minimum bandwidth of the system since the scan range is limited to a relatively small value (a 1.0-Mcs bandwidth would require 100 discrete levels, giving signal frequency automatically to a 1-Mcs resolution which is better than 0.004% at 18 Gcs); and last, but not least, the sweeping L. O. would be free of "spurs" caused by a true FM ramp. This second scheme is the one reported by VITRO (Ref. 34). However, the scheme suffers appreciably from vulnerability to spurious responses due to the several stages of mixing used.

2.4.5 Frequency Measurement. - The determination of received signal frequency can be made in several ways. The tuning of the receiver, being all-electronic, provides, in the tuning control voltage, an electrical analog of frequency. This can have an accuracy as good as 0.1% with rather elaborate schemes, though 1% is a more practical value. In the sweeping pan/sector mode, decade markers of any accuracy may be injected for display calibration. The two marker blips bracketing the signal could be determined automatically by rapidly sequencing an increasing decade resolution, on command by the computer, while the signal frequency is found by interpolation, as described below. See Fig. 2.4-1.

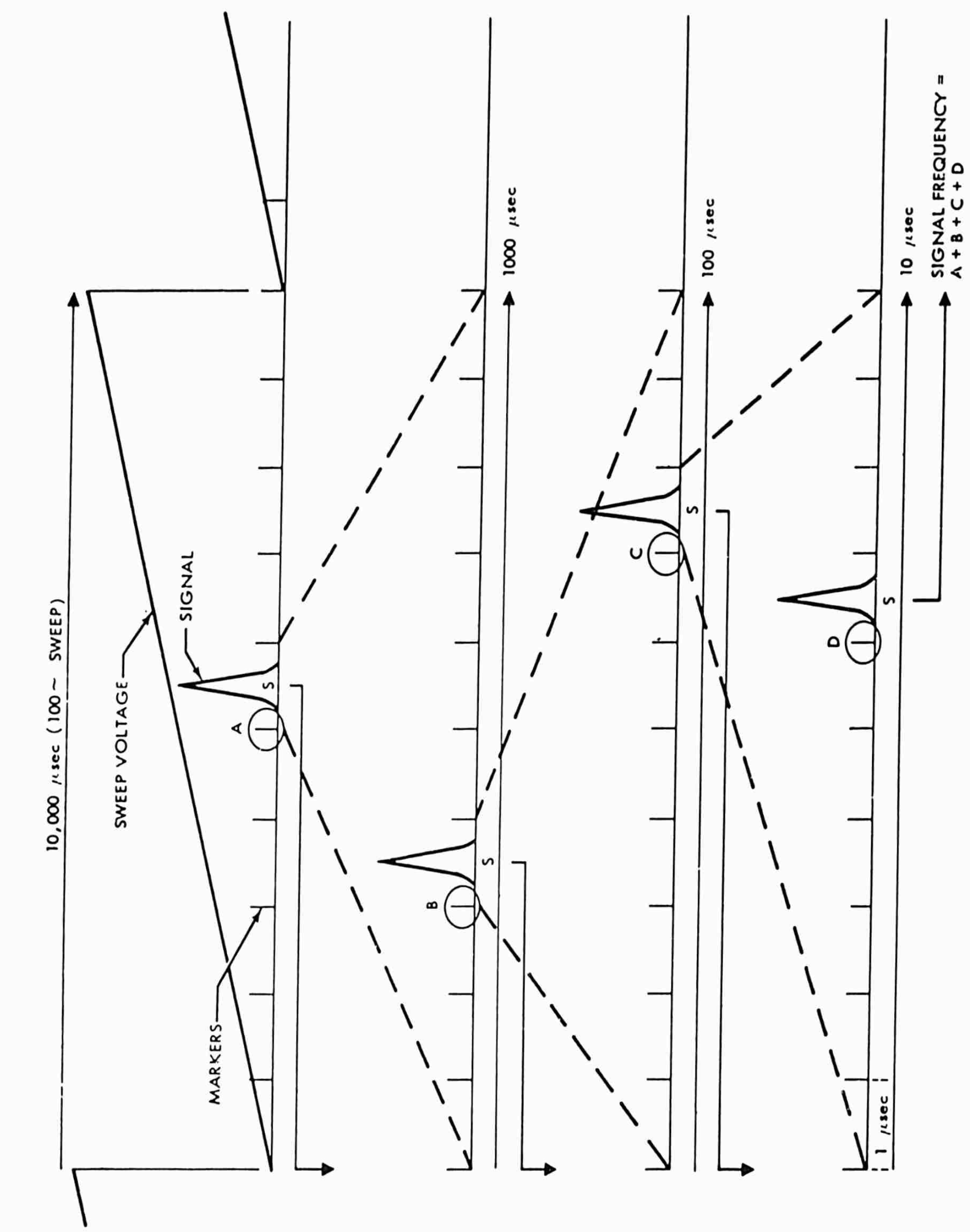
At the instant of signal coincidence on the sweep, the outputs of four decade counters, A, B, C, and D, are combined to give the signal frequency with A being indexed by correlation with the analog frequency voltage. The markers are all phase-coherent and feed the counters in parallel. The actual marker spacings would depend upon the Band in question as shown in Fig. 2.4-1. For this scheme to work, it is of course necessary to determine signal coincidence quite accurately. For CW, this is no problem, but for signals characterized by a broad spectral distribution, it becomes necessary to consider the spectral envelope. An operator, viewing the display, could position a strobe intercept at any desired point on the signal envelope. Fully automatic operation would require sensing the signal-spectrum peak. This method does not require further calibration.

It might be satisfactory to accept the 1% accuracy while sweeping, and then, when in the fixed-frequency mode, take the time to manually measure the L.O. frequency or a substitute signal from the calibration generator with a transfer oscillator and counter.

A third method, where the L.O. frequency is derived by a crystal controlled synthesizer, would provide continuous exact frequency information (See section 2.4.4 above).

2.4.6 Passive Tracking. - The antenna pedestal servo responds to azimuth and elevation error voltages derived by the receiving complex operating on the three r-f signals coming from the antenna/hybrid group. These are the sum (Σ), azimuth difference (Δ_{az}), and elevation difference (Δ_{el}). The Σ signal, besides yielding the normal data (frequency and amplitude), also acts as the phase reference for determining the sign of the difference-channel error signal. Therefore it is a design requirement that the Δ signal paths must exhibit a minimum of differential phase-shift relative to that of the sum channel. The maximum total phase error resulting from all causes including the summing and differencing hybrids should not exceed that value which causes a signal loss of 1 db. The AZ and EL error signal output is proportional to both the error signal amplitude and the cosine of the phase angle $\emptyset$ between the error signal and the reference at the detector. When $\emptyset$ is 0° or 180°, the detector output magnitude is a maximum with the plus or minus sign determined by phasing. A 1 db (12%) drop in output voltage would result from a 28° phase error.

The straightforward receiver configuration with completely separate channels for each of the Σ, Δ_{az} and Δ_{el} signals, but with a common L.O., would be a satisfactory design solution. However, a single difference channel, time-shared for Δ_{az} and Δ_{el} functions would be completely adequate so long as



TUNING VOLTAGE ANALOG FREQUENCY ± 1% / MARKER SPACING IN MEGACYCLES ACCORDING TO BANDS		
BAND 1	BANDS 2,3,4	BANDS 5,6
10	100	1000
1	10	100
0.1	1	10
0.01	0.1	1

Figure 2.4-1. Automatic Frequency Determination (Sweeping Mode)

the commutation rate exceeded the loop bandwidth (about 1/6 cps) by at least an order of magnitude. If it were not for the differential phase error in parallel paths, aggravated over the 2 to 1 tuning range, a simultaneous time-sharing could be done with Δ_{az} and Δ_{el} mutually orthogonal. However, axial cross-coupling would accompany this scheme in addition to the gain variation for differential phase variations between the Δ_{az} and Δ_{el} signals. Sequential time sharing does not have this added problem and is preferable.

Linear receivers using common AGC derived by the Σ channel would be mandatory. Logarithmic receivers could not be used since the Σ/Δ amplitude ratio varies over a wide range and the phase shift through a logarithmic amplifier is dependent on the absolute signal level.

A scheme whereby even the common Δ signal channel is eliminated, with all three signals multiplexed over one channel, is much to be desired. In such a scheme, the differential phase problem is reduced to the minimum and a considerable cost saving is realized. One method might combine the three signals according to Fig. 2.4-2. The Σ signal is "on" continuously. At an arbitrary angular commutation rate of 2^{ω}, the Σ signal is added with alternative Δ signals both shifted equally by 90°, which now bear a 0° or 180° relationship to the Σ phase, thereby directly adding or subtracting in amplitude. The Δ signals alternate at an angular rate which is 1/2 the $(\Sigma + \Delta)$ rate. After amplification, a simple envelope (AM) detector feeds a decommutator operating in reverse order to separate the signals. Their stretched values are compared, the comparator outputs providing the servo error signals. This system, however, departs from true (simultaneous) monopulse and is similar to conical scan, in that the reference-to-error comparison is time-sequential rather than instantaneous; scintillation would therefore become a problem. Though a commutation speed in excess of a few hundred cycles per second would normally overcome this difficulty, it would not be compatible with pulsed-signal repetition rates. Moreover, the crossover slope for conical scan is approximately one-half that of monopulse, all else being equal.

A time-multiplexing scheme which does not lose the true monopulse feature might be considered whereby the three channels are unequally delayed in a time "staircase", then sampled sequentially, amplified, decommutated and realigned in time. This technique is described in Reference 35 and indicated in the block diagram of Fig. 2.4-3. The problem is complicated by the fact that the incoming signals are not derived within the receiving equipment as in a radar. The full range of repetition rates must be accommodated for pulsed sources. It must also function on non-pulsed sources; a self-synchronizing switch with optional interval sync generator might solve the signal modulation diversity. A minimum time delay on the order of 10 microseconds, due to long pulses, prohibits the use of r-f delay lines, which means that the common channel must be restricted to use at the intermediate frequency. The r-f preamps would then be independent. The added complexity of this method offsets the saving of i-f amplifiers and does not warrant its application.

As a result of the above review of available techniques, the two-channel system discussed earlier is further considered. This scheme employs one full-time channel for the phase reference and one channel which is time shared between the Δ_{az} and Δ_{el} signals. This configuration is illustrated in the block diagram of Fig. 2.4-4.

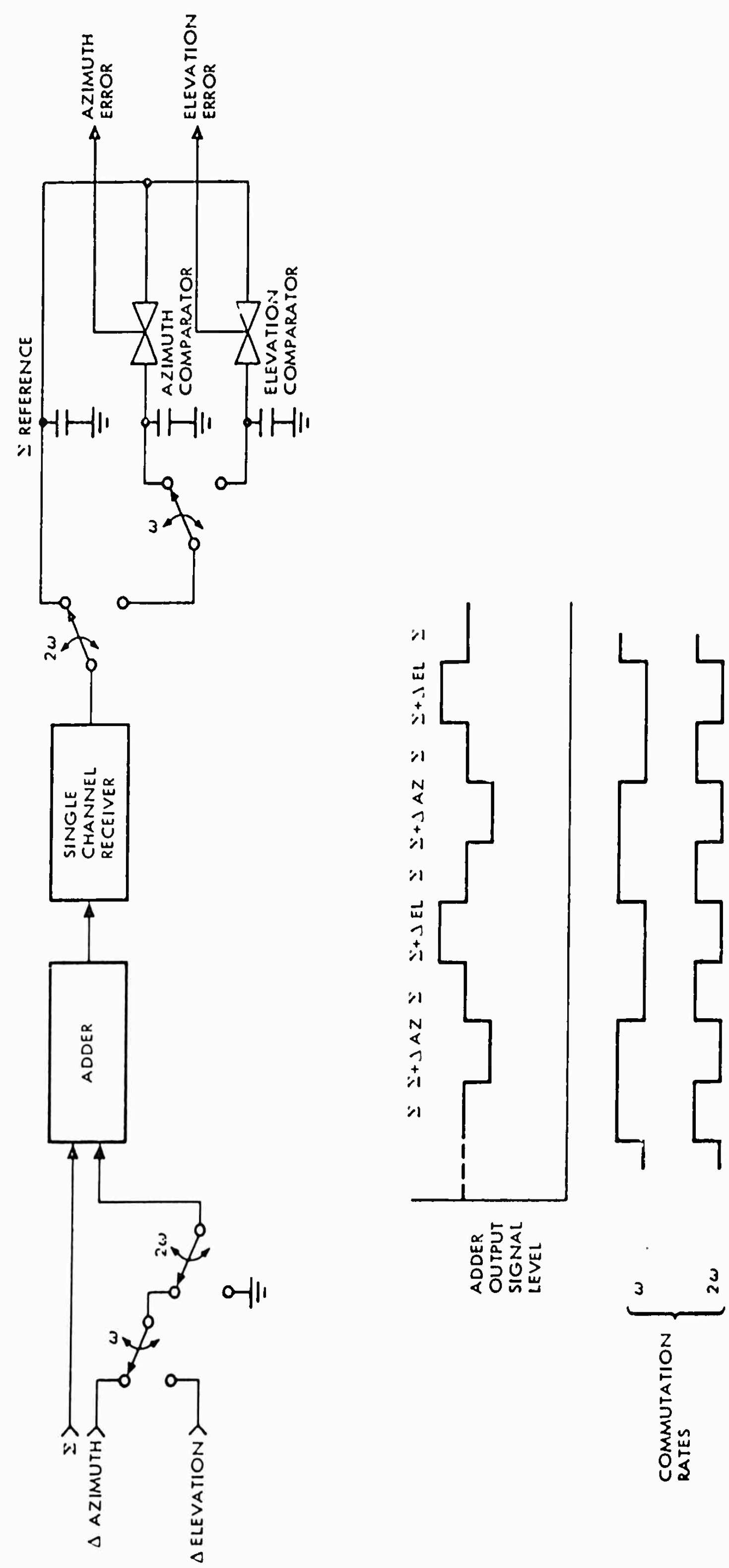


Figure 2.4-2. Single Channel Multiplexing System

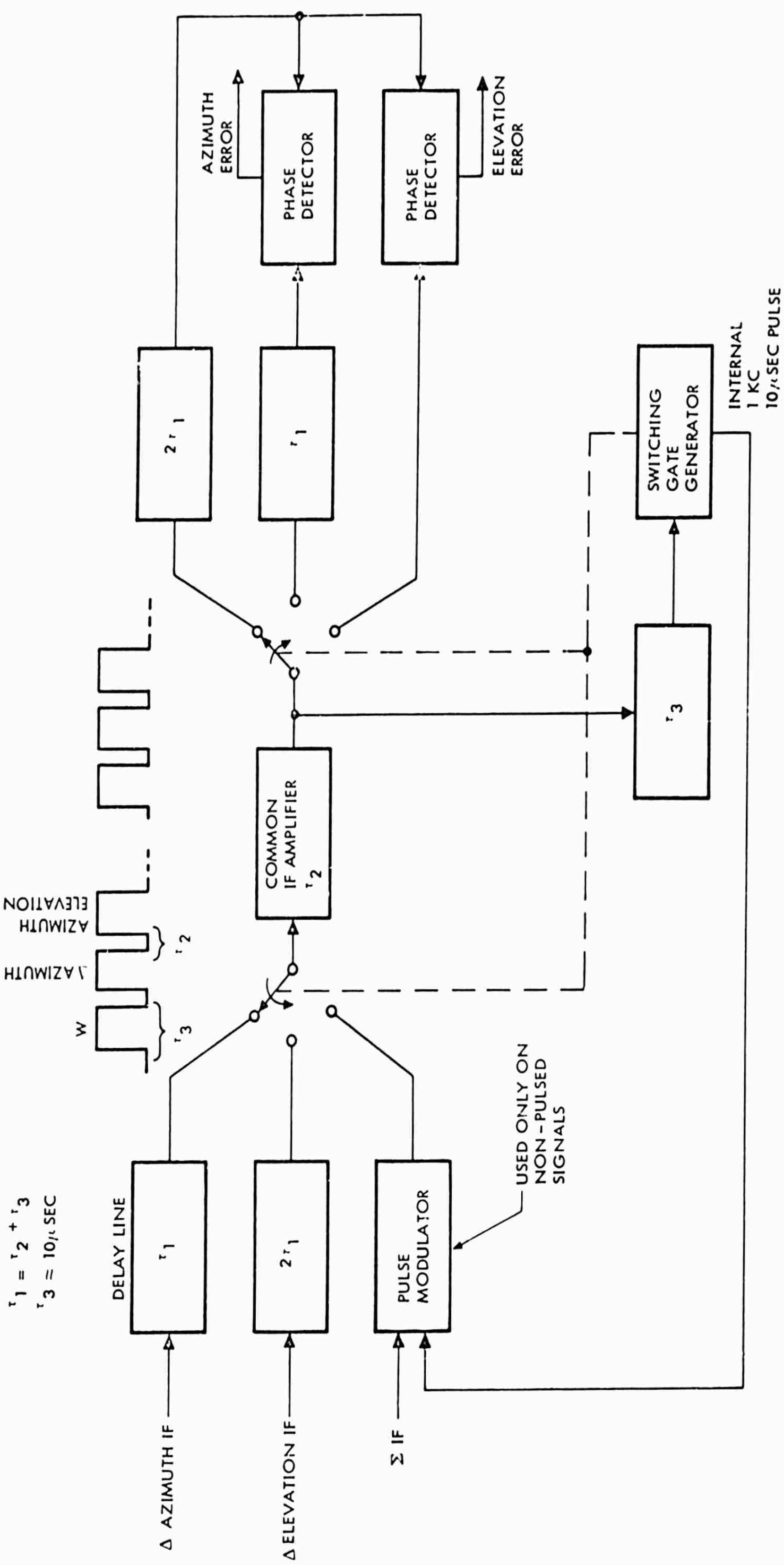


Figure 2.4-3. Time Multiplexing Monopulse Receiver

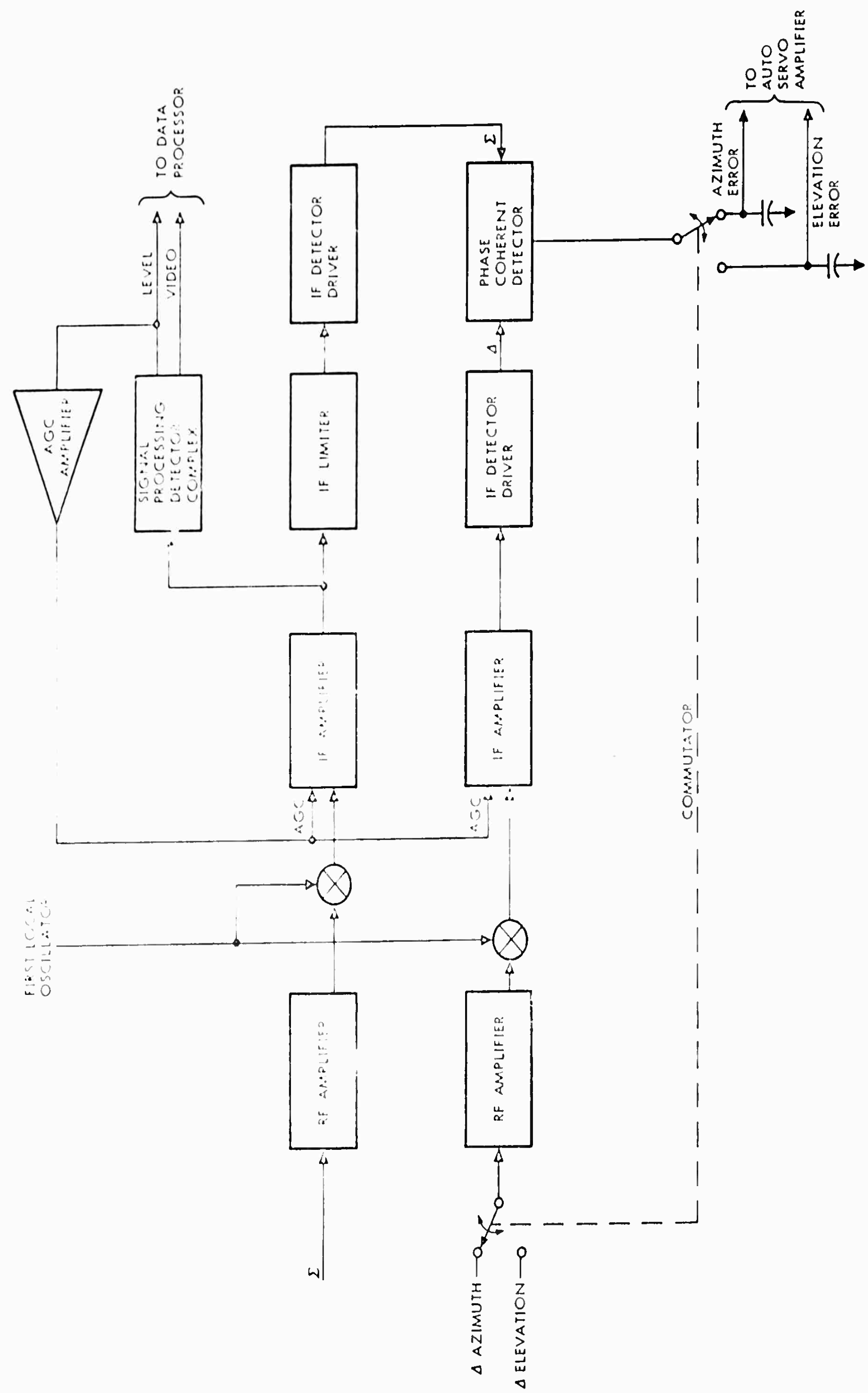


Figure 2.4-4. Two Channel Monopulse Receiver

The Σ and Δ channels should ideally have identical and linear gain and phase characteristics up to the AGC detector in the Σ channel. AGC action keeps gain equal in both channels up to this point, with the i-f levels essentially constant (for all r-f input levels) and equal to the AGC reference. The Σ channel is normally amplified further and then limited to more nearly approximate an "on/off" switching waveform for controlling the phase-coherent detector.

2.5 SIGNAL LEVEL AND FREQUENCY CALIBRATION TECHNIQUES

The problem of signal level calibration is related to that of frequency calibration only to the extent that they are both done at the signal frequency. Absolute level calibration involves substituting in place of the true signal another similar signal of equal level which can be measured. Since the amplitude response of the entire receiving complex is frequency sensitive, including the antenna array, it is desirable to make this substitution of signals at a point prior to the antenna. However, the establishment of a precisely known field strength at the antenna array by a remote radiator introduces several major problems. First, calibration cannot be done while tracking without interrupting the target signal; the antenna array would also have to be slewed around so as to be aimed at the reference beacon. It is also necessary to establish a long-run remote control at the beacon site for tuning the transmitter and setting its output level to a precisely known value. In addition, the beacon antenna pattern would call for corrections as a function of frequency, to be added to the calibrated value. All of these precautions, though rather costly, are not particularly difficult to accomplish. There is one problem, however, that does appear to seriously hinder the use of this system, namely that due to multipath interference.

In order to clarify this effect and point out its marked dependence on frequency and terrain, let us assume a typical beacon range of 2500 feet and antenna height of 40 feet; receiver antenna height will be assumed as 25 feet. Figure 2.5-1 shows this situation graphically.

The relative phase α, between the direct and reflected beams, is given approximately as

$$\alpha = \phi + \frac{4\pi h_1 h_2}{\lambda R} \qquad (2.5\text{-}1)$$

where

ϕ = the static component due to θ_R, the reflection angle.

Two simplifying assumptions are made: θ_R is small (1.49° in the example chosen), and the direct slant range R is very nearly equal to the horizontal base-to-base range. The angle $\gamma = \alpha - \phi$ is then the frequency-dependent component. By rearranging Eq. 2.5-1, we may solve for the frequency increment which would cause a 180-degree phase-shift, i.e., cancellation, or a multiple of 360 degrees, i.e., addition.

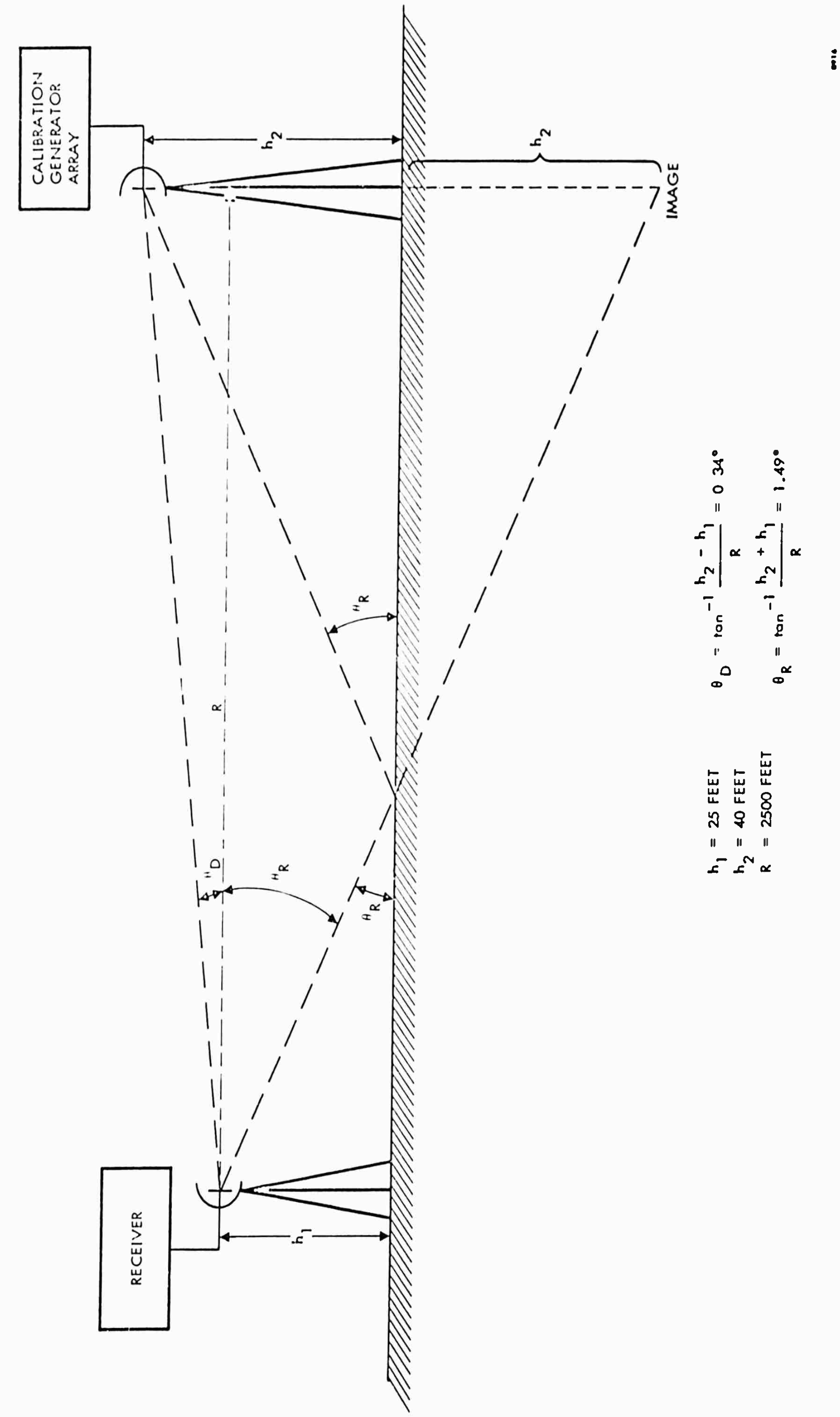


Figure 2.5-1. Typical Receiver and Beacon Site

$$\alpha - \phi = \gamma = \frac{4\pi \, h_1 \, h_2}{\lambda R} \tag{2.5-2}$$

Substitute c/f for λ, where c = velocity of light.

$$\gamma = \frac{4\pi \, f \, h_1 \, h_2}{c R} \tag{2.5-3}$$

Set $\gamma_1 = \pi$ and $\gamma_2 = 0$.

$$\gamma_1 - \gamma_2 = \pi = \frac{4\pi \, h_1 \, h_2}{c R} (f_1 - f_2)$$

Therefore,

$$\Delta f = f_1 - f_2 \frac{c R}{4 \, h_1 \, h_2} \tag{2.5-4}$$

$= 6.64$ Mcs for the typical values in Fig. 2.5-1.

When h_2/h_1 is not large, the denominator in Eq. 2.5-4 is larger by the addition of h_1^2, making Δ smaller. Thus, there is a complete phase reversal between the direct and the reflected beams for every Δf of 6.64 Mcs or less.

Normalizing the direct-beam field strength F_D to unity, the following equation defines the relative resultant field strength F as the vector summation of the direct (F_D) and reflected (F_R) components.

$$F = \sqrt{F_D^{\,2} + F_R^{\,2} \rho^2 + 2\rho \, F_D \, F_R \cos \alpha} \tag{2.5-5}$$

The reflection coefficient ρ, versus grazing angle, is given in Fig. 2.5-2 for various types of terrain. Taking typical values of ρ for 4 to 18 inches of grass at 10 cm wavelength, for both horizontal and vertical polarization, we get $\rho_h \approx 0.4$ and $\rho_v \approx 0.1$. F_R is the receiving antenna gain at an angle off beam center equal to $\theta_D + \theta_R = 1.83°$, and is a function of beamwidth. (The radiating beacon antenna is assumed very broad.) The angle α is taken at its limits of 0° and 180°. Equation 2.5-5 is now solved for various beamwidths in both polarizations. The ratio of ($F_\alpha = 0$ / $F_\alpha = \pi$) in db is plotted versus beamwidth for H and V in Fig. 2.5-3.

It is seen that the H variations are the greater (almost 7 db) while the V fluctuation is only 1.5 db.

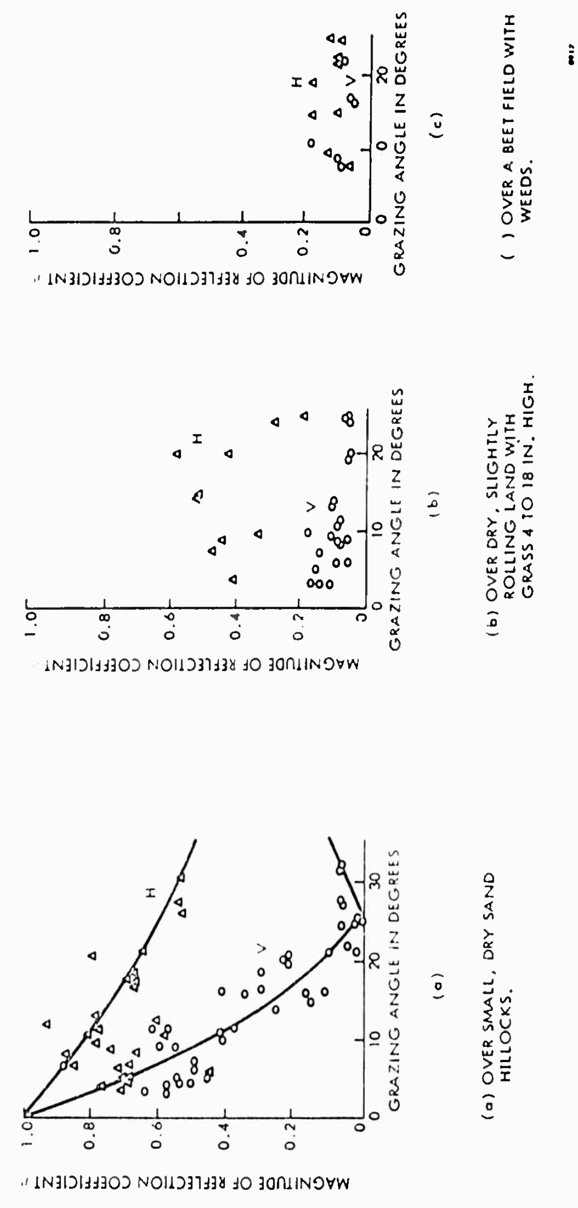


Figure 2.5-2. Horizontal and Vertical Polarization Reflection Coefficients vs Grazing Angle for Various Terrains

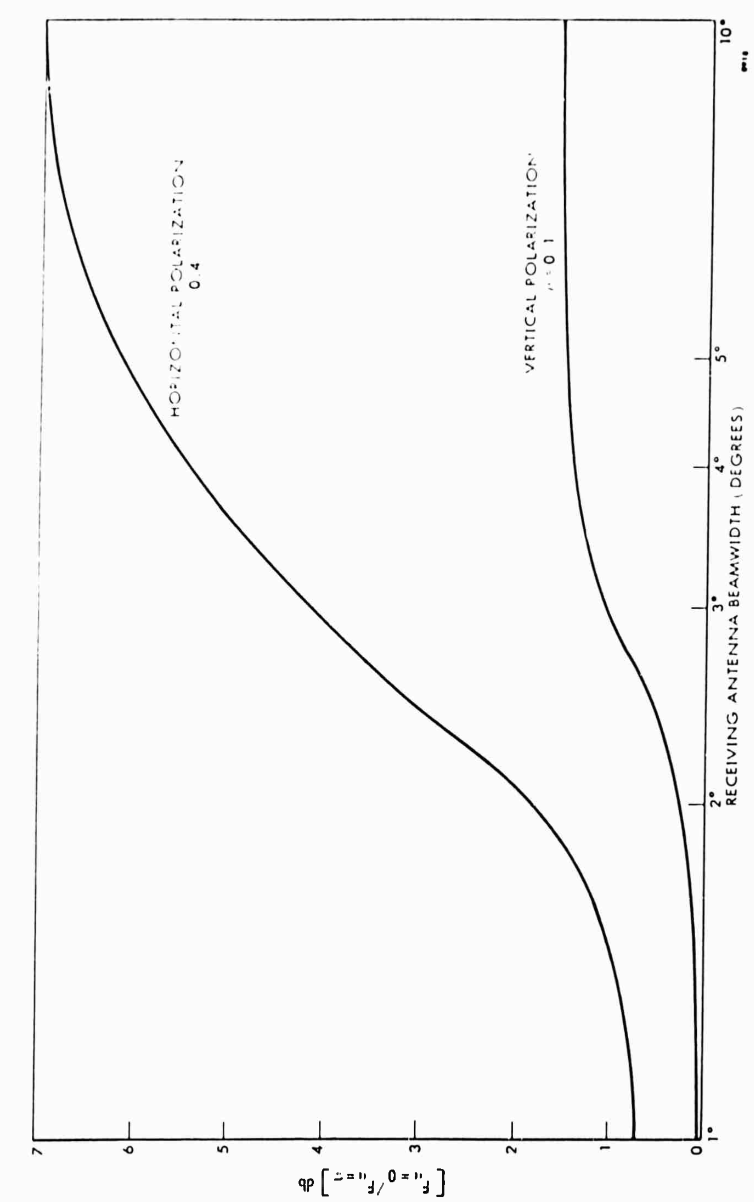


Figure 2.5-3. Variation of Expected Signal Level from Remote Calibration Generator as a Function of Receiving Antenna Beamwidth

The situation as regards true signal reception is only slightly better, inasmuch as a typical elevation angle, θ_D, of 3.76° occurs for R of 25 nautical miles and altitude of 10,000 feet.

The appreciable H variation might be compensated by sweeping the beacon across Δf, provided the receiver bandwidth is flat over this range. The average level would be that due to the direct wave only.

Rather than using a pole beacon, an alternative calibration scheme employing injection at the receiving antenna terminals appears attractive for three important reasons:

a. Multipath interference is eliminated.

b. Calibration may be done while tracking.

c. Rotating joint specifications on transmission versus rotation are relaxed since this is now within the calibration loop for any given azimuth angle.

The second point allows for dynamic comparison between true and calibration signals on an equal-level basis. This avoids reliance on the linearity of both the overall receiver dynamic range and that of the signal detector. Another point in favor of this method is the elimination of the need to interpolate between discrete levels established by a calibration check made at some other time. Problems common to both systems are:

a. Corrections for small signal-level variations versus frequency.

b. Establishment of reference level.

c. Precise determination of attenuation following the reference level point.

The reference level generator array, regardless of location, must be electrically tunable; its output reference level must be maintained constant; the reference level must be attenuated through a precision attenuator with the attenuation level available in a form suitable for readout.

For reasons given earlier in regard to the receiver first L.O.'s, the signal generator array should incorporate BWO's, but some other scheme must be found for Band 1 since BWO's are impractical under 500 Mcs. It appears that, in order to avoid band switching and its associated problems, the use of three separate signal generators with motor-driven tuning is the only practical solution for Band 1, with one output for each of the sub-bands as follows:

Sub-Band	Coverage, Gcs
1A	0.1 - 0.225
1B	0.225 - 0.5
1C	0.5 - 1.0 (a BWO is possible)

No single commercially available unit has been found which is ideally suited for such operation.

The reference levelling setting is best established automatically. The range of control required is not great, some 10 db at most. A voltage-controlled solid-state attenuator is commonly used for this purpose.

The critical point is at the level-sampling diode, its housing, and the associated couplers. Levelling to within ±0.5 db is possible through X Band, with special diodes (discounting the coupler variations), which have response typically constant within 1.5 db across an octave band for a nominal 3 db coupling. This means that the output reference level might have as much as a 2 db variation with frequency. This represents the best that can be done without resorting to variable impedance match refinement across each band. Fortunately, the major error contribution is generated by the coupler, which is passive and constant with time. Therefore, a small correction can be introduced into the levelling control loop as a parametric function of tuning voltage.

The best precision attenuator accuracies achievable vary from ±2% for Band 6 to ±1/2% for Band 1. They are given below for Bands 1 through 6 with the attenuator type indicated (Ref. 9).

Band	Accuracy	Attenuator Type
1	±1/2%	Waveguide beyond cutoff
2	±1/2%	Waveguide beyond cutoff
3	±1%	Waveguide beyond cutoff
4	±1%	Waveguide beyond cutoff
5	±2%	Rotary vane
6	±2%	Rotary vane

For remote operation, the attenuator shaft can be servo driven, its position being determined by a coupled shaft-position encoder with appropriate digital readout. Extension to automatic attenuator drive would include completing a positional servo loop. Since the calibrate sample is to be made equal to the true signal, a comparator must monitor the difference. A typical channel-level-calibration system is shown functionally in Fig. 2.5-4. The comparator takes the form of a differential amplifier. Commutation, with separate holding amplifiers, prevents an initially large calibrate signal from capturing the AGC loop and disturbing the passive tracking function. The tracking loop bandwidth has not been specified but will most probably lie in the vicinity of 1 radian (1/6 cps). The calibrate signal sampling rate should be not less than 5 to 10 times the data rate, which has been specified as 5 per second. The duration of the calibrate signal should be small, so as to maximize data signal time. It may be that the data signal is pulse-modulated and at least one new signal pulse should be received between calibrate samples. The minimum repetition rate for most similar systems is on the order of 100 pps.

The calibration gate generator would ideally put out a 1-millisecond pulse at a repetition rate of 50 pps, with the 19 millisecond "off time" devoted to data-signal reception.

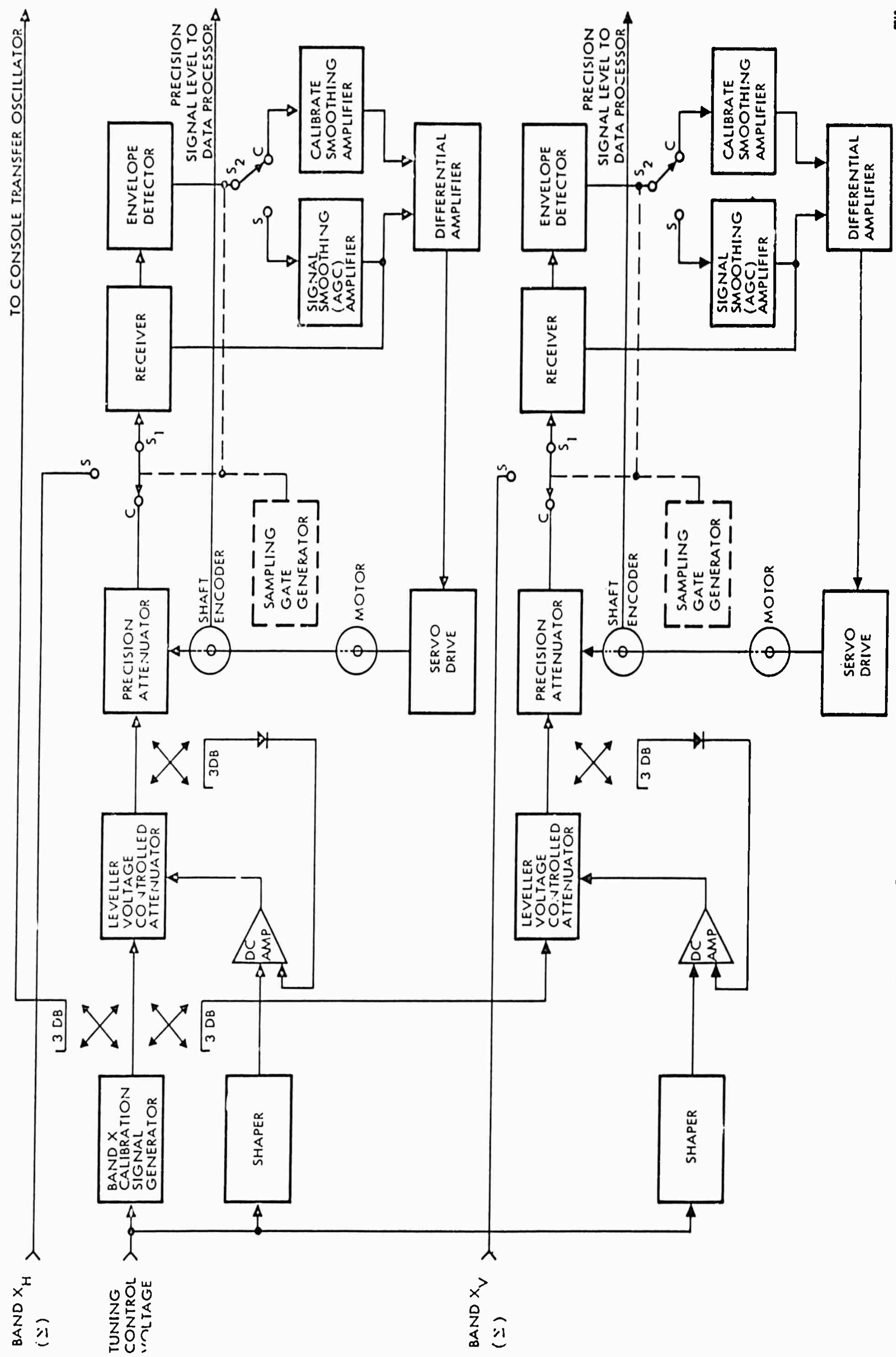


Figure 2.5-4. Typical Band Level Calibration System

Switching of r-f signals according to the above format calls for the use of non-mechanical devices. PIN (intrinsic layer) diode switches do not appear to be usable above 6 or 7 Gcs, but are quite suitable in SPDT versions below this range. An alternative scheme is shown in Fig. 2.5-5. This is a new application of the standard radar duplexer circuit. When the shunt diodes in S1 and S2 are open, the antenna signal is passed to the receiver with very little attenuation (on the order of a tenth of a db), and the signal generator output is passed to the dummy load. When the diodes are shorted, the antenna signal is reflected to the dummy load while the signal generator output is reflected to the receiver with a typical loss of 1/2 db ±1/10 db. Isolation for both conditions is normally around 40 db. Octave band coverage may deteriorate this to between 25 and 30 db at the band edges; a 1% isolation (20 db) is satisfactory. The diode switches S1 and S2 would be driven by the Sampling Gate Generator.

The solution to the frequency calibration problem depends on the choice of receiver configuration. The tuning voltage for a BWO is the analog of frequency, and is consistently repeatable. Its linearity and accuracy are both on the order of 1%. The use of calibration markers during BWO scanning can yield crystal-controlled accuracies. So also does the use of synthesizer-derived L. O. frequencies as described earlier in Sec. 2.4-4, which yields crystal accuracy in both the sweeping and non-sweeping modes. Receivers using BWO's as first L. O.'s in the non-sweeping mode require that a transfer oscillator and counter be used to determine the frequency to any accuracy better than the above-mentioned 1%. For convenience, the substitute calibrate signal (CW) may be measured by the counter for a direct reading of incoming signal carrier frequency; it appears impractical to automate this particular function, inasmuch as the use of a transfer oscillator requires the operator to decide on the correct harmonic number.

2.6 DATA PROCESSING

The function of the data processing system is to accumulate all pertinent data from the receiving and tracking systems, and aircraft altitude information, and to perform such computations as are required to define the radiation characteristics of the airborne system under test. The determination of radiation patterns will be the primary function of the processor. A secondary function will be to provide a measurement of field strength of the radiating systems as a function of frequency, or the frequency signature. Inasmuch as system considerations necessary to accomplish radiation-pattern measurements necessarily encompass those of frequency-signature measurements, the following will be a discussion of system considerations for the primary role of radiation-pattern measurements.

The radiation pattern will be determined by computing the direction and magnitude of an r-f vector emanating from the source of airborne radiation relative to the conventionally defined coordinate axes of the airborne vehicle. The direction of the r-f vector with respect to the airborne vehicle coordinates can be readily determined from knowledge of the vehicle's range-elevation position and the aircraft's attitude (or orientation of aircraft axis coordinates) relative to the fixed coordinate system of a ground-based receiving antenna. The absolute magnitude of the vector can be determined if an accurately calibrated receiving system is used. The magnitude of the vector can be normalized for a particular range by means of a relatively straightforward computation.

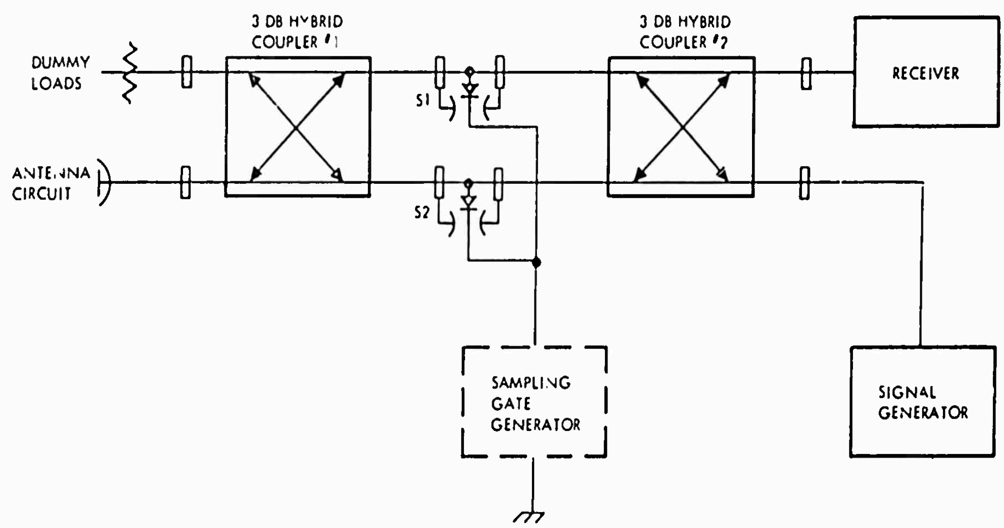


Figure 2.5-5. R-F Switch for Bands 5 and 6

The data processing system should be independent of the type of flight pattern, except as limited by the data-handling capacity of the data processor. A discussion of data-handling limitations is deferred to a latter section of this report. For the purpose of discussion of the problems of data processing, a cloverleaf flight pattern is assumed.

The cloverleaf flight pattern is one in which the aircraft is vectored to fly at various headings through a designated identification point (I. P.) in space at a constant altitude, as shown in Fig. 2.6-1. During each flight through the I. P., data will be gathered to determine characteristics of a particular point on the radiation pattern of each airborne system undergoing test. A series of flights at a constant altitude and range will result in a radiation pattern at a corresponding depression angle, related to aircraft coordinates. Patterns for other depression angles will be similarly determined from data gathered from a series of flights at other discrete altitudes corresponding to the desired depression angles, until the three-dimensional radiation pattern of the aircraft is described to the degree of detail desired.

Data are gathered during flight in three test zones defined as the Pre-test, Test, and Post-test zones, as shown in Fig. 2.6-2. The Test zone is approximately 500 feet wide in contrast to approximately 5 nautical miles each for the Pre-test and Post-test zones. Assuming an aircraft ground speed of 300 knots, the period of time required to transit each test zone is as follows:

1.	Pre-test	60 seconds
2.	Test	1 second
3.	Post-test	60 seconds

The required data to be taken during the entire data run is listed in Table 2.6-1. It will be noted that aircraft tracking data (azimuth, elevation, and range) are monitored throughout the data run. During the Pre-test period, the aircraft's course is computed to permit an accurate vectoring of the aircraft into the test phase. Aircraft course during the Test and Post-test periods is computed to assure that the aircraft course is that desired. During the Test period, all data pertinent to determining points on one or more radiation patterns associated with respective sources of radiation are monitored at the rates indicated.

In addition to time of day and tracking data, the frequency of each horizontal and vertical receiving band is monitored during the Pre-test and Post-test periods to provide a ±1% record of the receiver bands used. The identification of frequency is of prime importance when the system is used in spectrum analysis. One sample at each frequency is monitored during the Post-test period immediately following the test period to insure that the respective tuning of each receiving band is consistent with that prior to the Test period. Inasmuch as the stability of the receiver is measured in terms of cycles of drift per minute or longer, a sample of each receiver band frequency may be taken at relatively low rates. For convenience, frequency sampling at the rate of one sample per second is assumed.

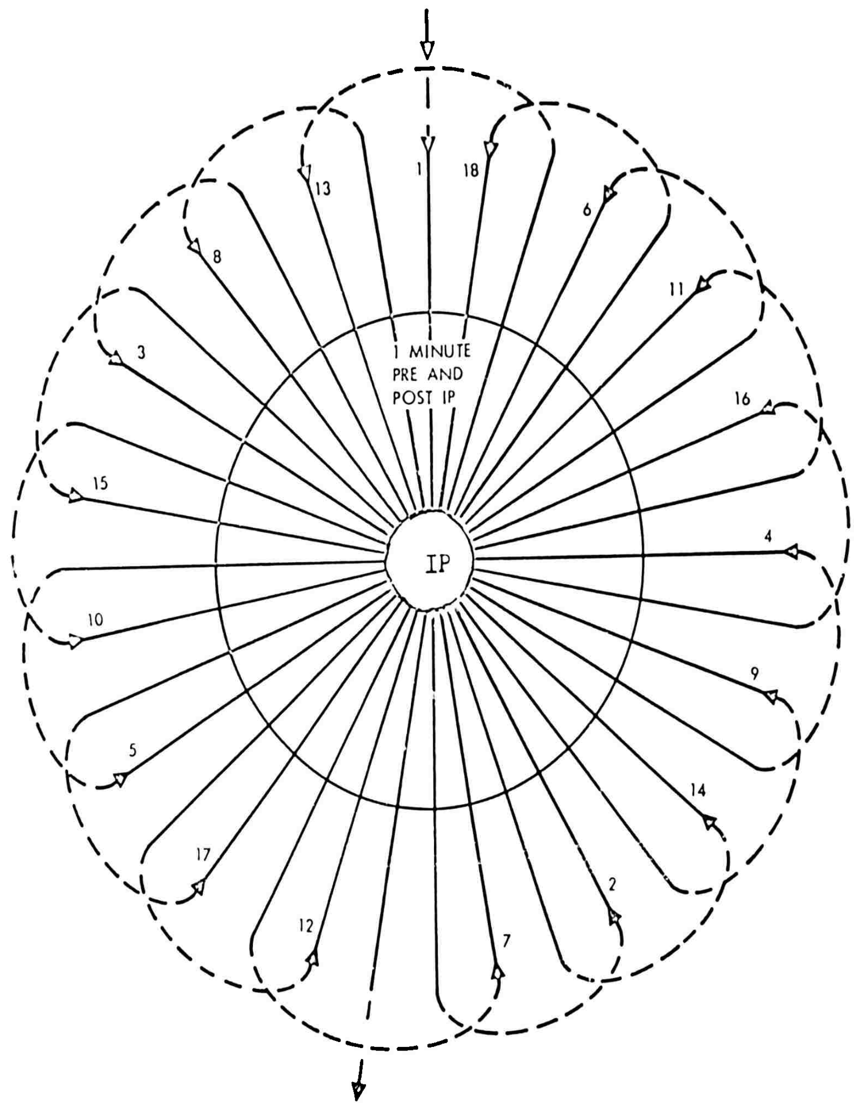


Figure 2.6-1. Typical Flight Plan for Cloverleaf Pattern

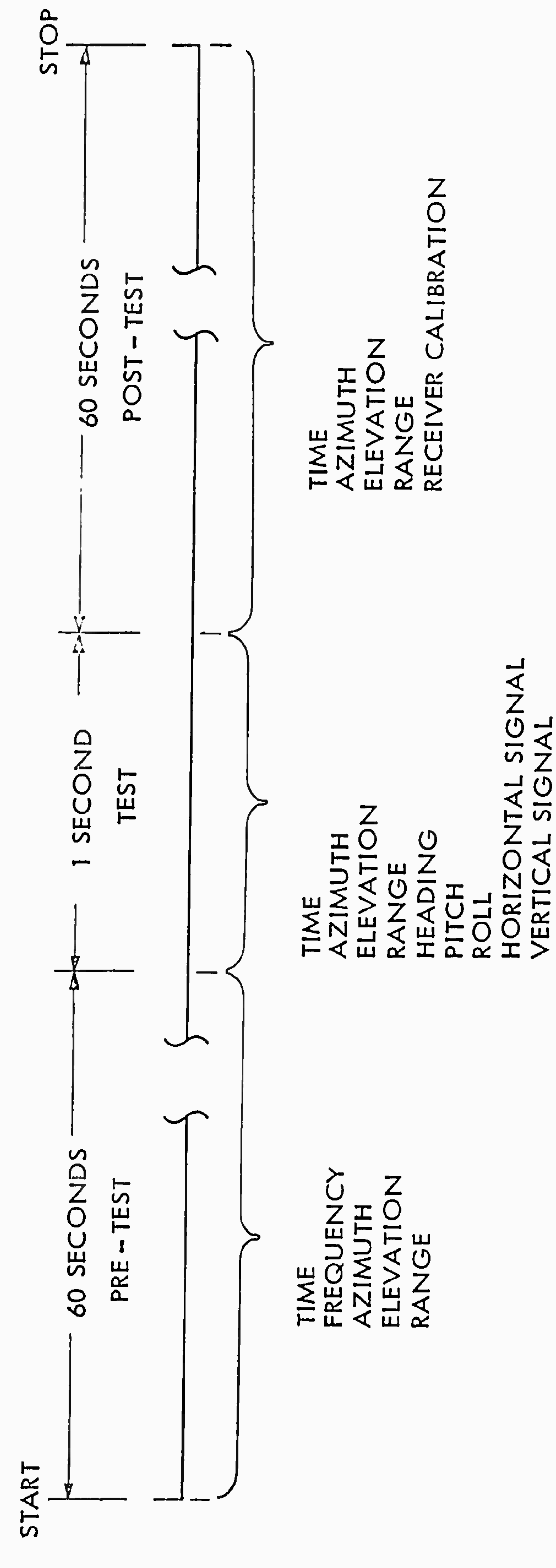


Figure 2. 6-2. Timing Sequence of Cloverleaf Pattern Data Run

TABLE 2.6-1

DATA SAMPLING RATES

Parameter	Period			Sample Rate CPS	*Number of Samples
	Pre-test	Test	Post-test		
Time	x	x	x	1	121
Aircraft Azimuth	x	x	x	5	605
Aircraft Elevation	x	x	x	5	605
Aircraft Range	x	x	x	5	605
Aircraft Heading		x		5	5
Aircraft Pitch		x		5	5
Aircraft Roll		x		5	5
#Abs. Hor. Signal Level		x		5	5
#Abs. Ver. Signal Level		x		5	5
#Hor. Frequency	x		x	1	62
#Ver. Frequency	x		x	1	62
#Hor. Calibration			x	1	10
#Ver. Calibration			x	1	10

#Values are for one receiver band.

*Assuming a one-second Test period and 60 seconds for each Pre-test and Post-test period.

It is desirable to determine absolute power levels of signals received in each horizontally and vertically polarized receiving band. In the event that absolute levels cannot be readily measured, a calibration run of each receiver should be provided during the Post-test period. A calibration run is valuable in any event, as it permits a dynamic check on the validity of signal levels monitored.

The determination of the direction of each r-f vector relative to the coordinate axes of the aircraft requires the solution of complex trigonometric equations (see Appendix IV). In the general case, it is assumed that the aircraft's range, azimuth, and elevation is determined by a tracking system external to the receiving system. Curvature of the earth must be taken into consideration to permit an accurate determination of aspect and depression angles independent of the aircraft's range.

Fundamental to ascertaining the aspect and depression angles relative to the coordinates of the aircraft is an accurate knowledge of the heading, pitch, and roll attitudes of the aircraft. In the absence of automatic airborne instrumentation and an air-to-ground data link system, it will be necessary to resort to human interpretation and communication of the desired aircraft altitude data. It follows that errors in the plot of the radiation pattern can result if the data is reduced utilizing data which is subject to potential misinterpretation and subsequent communication.

Aircraft which is equipped with an automatic pilot can maintain the average angular error in heading, pitch, and roll for straight and level flight to less than 1° throughout any one data-taking test run. Consequently, if sufficient data is gathered and properly smoothed, the pitch and roll of the aircraft can be considered to be constant and of zero magnitude, thereby reducing the complexity of computations required to determine the aspect and depression angles. When the duration of a single test flight is such as to cause major changes in gross weight of the aircraft, the constantly changing trim conditions will cause a slowly-changing pitch reference error. This can be overcome through adherence to simple flight-operational procedures, as discussed in Sec. 3.1.2, to preserve the 1° accuracy assumed.

The selection of an optimum approach to the data processing system is possible once the basic criteria of data rate and the desirability of real-time data reduction has been established. Obviously the desirability of real-time data reduction at high input data rates must be weighed against associated cost in terms of equipment complexity and reliability.

A fundamental objective of the data processing system is to reduce all data to the desired accuracy in a reasonably short period of time with a minimum of human participation. The volume of data that must be reduced is closely related to the data rate and to the required system accuracy. It will be noted that the volume of data indicated by Table 2.6-1 and complexity of computations required is such as to dictate the use of a computer as the basis of data processing.

It follows that a major decision must be made in regard to the application of the computer "on" or "off" line. If the computer is operated "on line" or as an integral part of the AN/MSQ-16 data processor, real-time data reduction is feasible. If economic considerations dictate the use of a computer facility "off line", the AN/MSQ-16 data processor design will be grossly affected.

The principal advantages of "on line" computer utilization are as follows:

1. Provides real-time data reduction.

2. Provides a flexible data-processing system adaptable to a variety of aircraft patterns.

The value of data reduction on a real-time basis cannot be overemphasized. Antenna patterns can be plotted during the test, thereby permitting an appraisal of the validity of the data while the aircraft is aloft. Data points which may be thought to be questionable can readily be rerun. Consequently, aircraft flight time can be utilized more efficiently.

The data processing system can be programmed to accommodate a variety of aircraft patterns, thereby making maximum utilization of the computer. On the other hand, if the computer is not operated "on line", the data must be processed and recorded in a fixed format compatible with the computer facility. When the computer is used "on line", it is possible to program the computer hardware to accumulate the data in accordance with the flight pattern dictates. Consequently, the "on-line" use of the computer permits optimum utilization of the computer as well as the aircraft. Two approaches corresponding to the "on-" and "off-line" use of the computer have been considered and are discussed in the following text.

A basic question arises as to the choice between the use of an analog or digital computer. The choice of a digital computer becomes obvious after considering the size, weight, complexity, and cost of an analog device of equal capability relative to a digital computer. The above comparison becomes even more favorable to a digital computer when the reduction of data on a real-time basis becomes a requirement, in that real-time data reduction by means of an analog computer precludes time sharing of a multiplicity of input data. In addition, analog computation would entail development of a special-purpose computer especially designed for the solution of problems inherent in the AN/MSQ-16 system.

2.6.1 Input Data Processing. - A requirement of input data processing exists independent of whether the computer is used "on" or "off line", since in any event it is necessary to process all input data into a form compatible with the computer. It will be noted that with the exception of time of day, which will be derived from the AN/USQ-23V, and possibly aircraft attitude data communicated via a digital data link from the aircraft, all input data will be in the form of analog voltages or shaft positions. Inasmuch as the use of a digital computer is indicated, it becomes necessary to digitize all analog input data to an accuracy which will not introduce a significant degradation of the input data.

As noted previously, the input data will consist of data from 6 receiver bands, the radar tracker, and aircraft attitude data. The tracking data shall be derived from the AN/MSQ-1A or AFMTC Mod III tracking systems which derive range, azimuth, and elevation of the aircraft as functions of shaft positions with the following accuracy:

Parameter	Accuracy
Range	1 part in 1,000
Azimuth angle	(1 part in 6,400) x 2π radians
Elevation angle	(1 part in 6,400) x 2π radians

Receiver data from each of the 6 receiving bands shall have the following accuracy:

Parameter	Accuracy
Signal Level	±20%
Analog Frequency	±1%
Digital Frequency	±0.001%

Aircraft attitude data shall be assumed to be accurate to ±2° if derived by human interpretation and transmission or less than ±1° if derived by a data link system.

Binary-coded decimal (BCD) time data from the AN/MSQ-23V, having a resolution of 1 second will be used for the chronological time and to serve as the basis of correlating data between ground and airborne instrumentation.

The input data may undergo analog-to-digital transformation by any of several means. An immediate choice of conversion equipment is the use of shaft encoders for all parameter inputs in terms of shaft position, and voltage-analog-to-digital converters for other parameters which occur in the form of analog voltages. In order to preserve the inherent accuracy of analog input voltages the analog-to-digital converter should have nearly an order of magnitude better accuracy (three binary bits). When converting shaft position, shaft encoders having the same resolution as the raw data can be employed since they are directly coupled and provide a one-to-one correspondence with the raw data.

Aircraft attitude data, if available, via an r-f automatic data link, will probably be in the form of digital codes in serial form. Regardless of its form, it will be desirable to convert it to an appropriate binary code in parallel form for entry into the remainder of the data-processing system for compatibility with computer formats. The number of bits in the digital code will obviously be dictated by the accuracy of the data link which will be assumed to be the same as that of the radar tracking data. In the absence of an automatic data link, the aircraft attitude data will be voice communicated, and can be readily entered into the processor manually.

It will be noted that the r-f frequency of each receiver band is available in two forms, one having an accuracy of ±1%, the other an accuracy of ±0.0001%. The more precise frequency measurement will be determined manually by means of a transfer oscillator technique which may require several minutes of operator time. The less precise measurement may be determined automatically by means of an analog voltage which will be shaped to provide a linear indication of the respective calibration frequencies of each receiver band to an accuracy of ±1%.

Since the rate of determination of the precise receiver frequency is severely limited by manual measurement, the precise value of receiver frequency will of necessity be manually entered into the processing system prior to the data run. The measurement of frequency having lesser accuracy, sampled at the rate of 1 sps, will provide a dynamic monitor of the tuning of each band for purposes of receiver band identification and correlating signal levels with frequency in the frequency-signature mode of operation.

An important consideration in converging on an optimum approach to the data processor system is the desirability of utilizing the processing equipment to the maximum feasible extent. The possibility of time sharing a common component with common inputs appears attractive, particularly in the processing of the relatively low-accuracy and low-bandwidth receiver data. Although the bandwidth of the radar tracking data is low relative to the 5-cps sampling rate, the accuracy of the high-order aspect and depression-angle computation would be degraded significantly if time-sharing of processing equipment were to be employed.

In view of the aforementioned considerations, it appears than an optimum approach to the initial processing of input data would be to employ an analog-to-digital converter on a time-shared basis to convert signal level and frequency of each horizontally and vertically polarized receiving channel to an accuracy of 1 part in 1024 as dictated by the received frequency. Radar tracking data can reliably be converted to this accuracy by utilizing shaft position encoders having ten or more bits.

The selection of a code for the digitized data has been carefully considered. The computer can accept a variety of codes; however, the computer program will require a transformation into a straight binary code for computations. The conversion time requires an insignificant amount of computer time on the order of milliseconds or fractions thereof as compared with a 200 millisecond minimum sampling period. Consequently, the choice of digital code can be made with little or no considerations of the computer.

From the standpoint of monitoring any of the input data, it is obviously desirable that all data be displayed in decimal form. The problem of displaying binary coded decimal readout is readily resolved if the computer is operated "on line" since the computer, upon request, can readily accomplish the conversion of input data if necessary. If the computer is operated "off line", it will be desirable that all input data be digitized in a binary-coded-decimal format. Monitoring of receiver data is straightforward in that the analog-to-digital converter can be designed to output any desired code. Similarly, shaft encoders can be provided with code wheels providing various grey and/or straight-binary codes requiring readout equipment for each wheel provided. Binary-coded-decimal conversion of straight binary codes will require additional equipment to accomplish the conversion if the computer is not available "on line". Consequently, the decision to use BCD codes appears to be an optimum choice for the "off line" computer.

The following is a tabulation of the minimum number of binary bits required to maintain the accuracy of the input data in BCD code:

Parameter	No. of Bits
Signal Level	8
Receiver Frequency (Analog)	12
*Receiver Frequency (Digital)	16
Tracking Data	14
Attitude Data	14
Time	20

*Manually entered prior to data run.

The decision to use serial or parallel data entry to the computer is one which must be made after considering the trade-off of higher data rates at the expense of added equipment. It will be shown that the relative increase in equipment complexity required to provide a parallel readout is small in comparison to the advantages of higher data rate made possible. The advantages of high data rates will obviously permit a reduction in aircraft flight time if flight patterns are chosen to fully utilize the maximum data rate of the data processor. Consequently, the use of parallel sampling of data appears to be the logical choice.

2.6.2 Off-Line Data Processor. - The off-line data processing system is one in which the digitized input data described above is in a format compatible with a computer facility. Insofar as the AN/MSQ-16 data processor is concerned, the output will be in the form of a recording of the digitized input data in accordance with the following discussion. In addition to the recording medium, the data processor will require straightforward logical circuits to control the flow of recorded data in accordance with a controller to program the reading and recording of the various input data.

The detail design of the data processor is of necessity dictated by the recording rate, which in turn will influence the selection of recorder type. Potential requirements of a hard copy of each data run can also affect the choice in the recording medium to a significant extent. If a hard copy is required for a permanent record of the data run, the processor design is biased in the direction of punched paper tape recording, assuming recording rates are compatible.

If the data rate is in excess of the recording rates of the state of the art paper punch recorders, the use of a magnetic tape will be mandatory. If a magnetic tape is indicated with an off-line data processor, while requiring a permanent hard copy, it is apparent that the equipment costs may influence the use of a multiple magnetic tape of sufficient length to record the entire data run. In this case, hard copy can readily be obtained from the computer facility at the time of data reduction. If a computer is integrated into the system, hard copy can be an output from the computer in any desired form independent of its source of input.

Two systems have been under consideration, one of which utilizes a 5-level character recording; the other utilizes an 8-level character recording. A block diagram of a system employing an 8-level character recording is illustrated in Fig. 2.6-3. The block diagram of a system using a 5-level character recording differs from that of the 8-level character system primarily in the required read and record gating logic.

The design of the controller is directly affected by the fact that the type of data to be recorded is a function of Pre-test, Test, or Post-test periods of the data run. A close examination of the problem reveals that the general design of the controller should be such as to provide a series of gates arbitrarily designated as "A", "B", "C" and "D" gates, which, when used in a combination of logic circuits, can be used to read and/or record any particular parameter at the rates and periods indicated by Table 2.6-1. Results of a detailed analysis of the number of various gates required for either 5-level or 8-level character recording is given in Tables 2.6-2 through 2.6-7.

Specifically, "A" gates are for the purpose of controlling the type of data to be read and recorded during the Pre-test, Test and portions of the Post-test periods as follows:

"A'" Logic Gates

Gate No.	Function	Time of Occurrence in Secs After Start of Data Run	Period
A'	Pre-test Period	0	60 secs
$A_{2'}$	Test Period	60	1 sec
$A_{3'}$	1st second of Post-Test Period	61	1 sec
$A_{4'}$	2nd	62	1 sec
* $A_{5'}$	3rd	63	1 sec
		64	1 sec

* 5-level character printing only.

Any one of five "D" gates each having a period of 200 Ms (as limited by the maximum sampling rate of 5 cps) can be used in combinations of "and" circuits to control the reading and recording of data on a macroscopic scale as shown by Table 2.6-8. Any particular input parameter is selectable by a "B" gate, the period of which is such that the sum of all the periods of all "B" gates is equal to the duration of one "D" gate, or 200 Ms. The number of "B" gates is governed primarily by considerations of convenience and the maximum number of characters to be recorded during any portion of the data run. The primary function of the "B" gate is to permit reading any one or group of parameters into the processor. Specifically, the first "B" gate

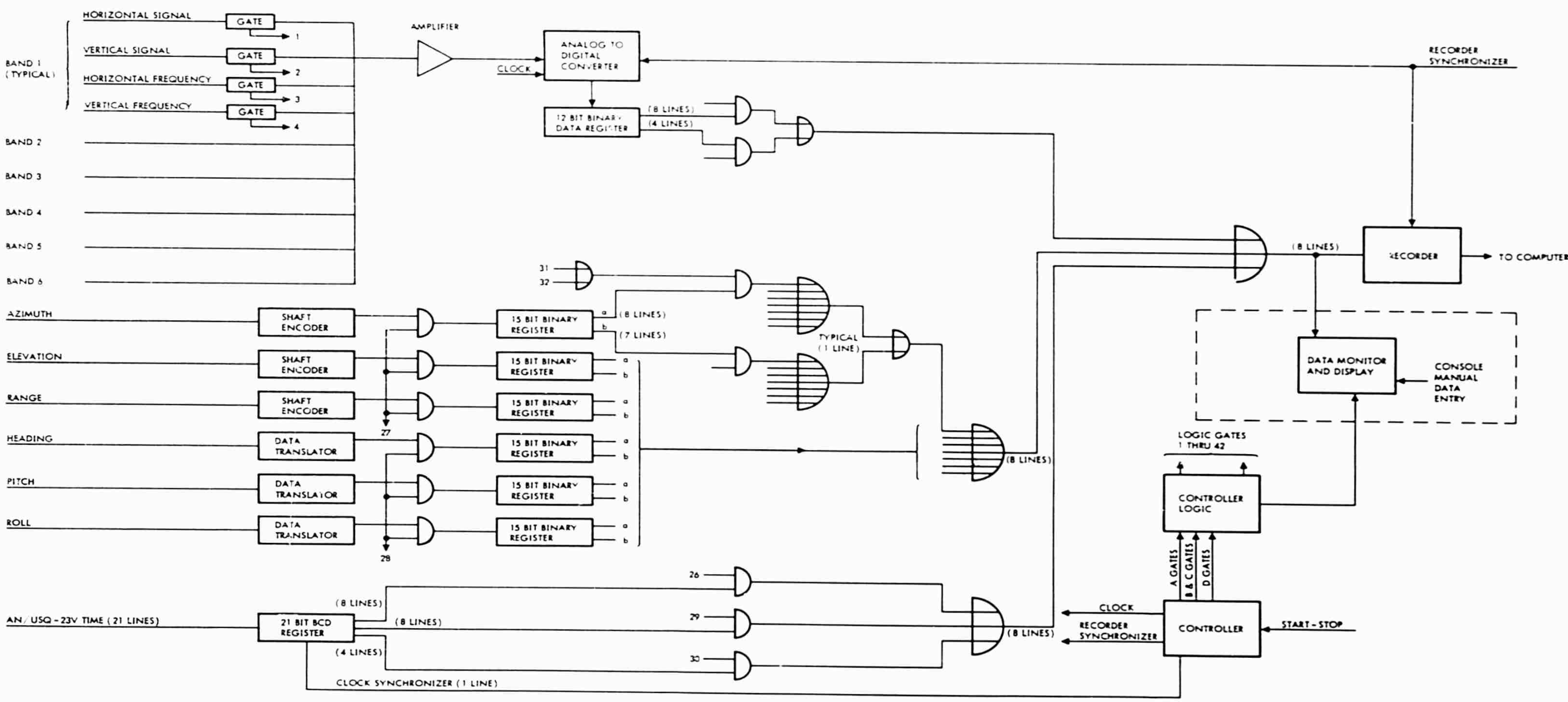


Figure 2.6-3. Block Diagram of Off-Line Data Processor

TABLE 2.6-2

"B" LOGIC READ GATES

(First 200 Ms of Pre-Test and Post-Test Periods)

5-Level Character Printing		8-Level Character Printing	
Gate No.	Function	Gate No.	Function
B_1	Time, Tracking Data	B_1	Time, Tracking Data
2		2	
3		3	
4	Hor. Freq. Band 1	4	
5	Ver. Freq. Band 1	5	
6	Hor. Freq. Band 2	6	
7	Ver. Freq. Band 2	7	
8	Hor. Freq. Band 3	8	
9	Ver. Freq. Band 3	9	Hor. Freq. Band 1
10	Hor. Freq. Band 4	10	
11	Ver. Freq. Band 4	11	Ver. Freq. Band 1
12	Hor. Freq. Band 5	12	
13	Ver. Freq. Band 5	13	Hor. Freq. Band 2
14	Hor. Freq. Band 6	14	
15	Ver. Freq. Band 6	15	Ver. Freq. Band 2
16		16	
17		17	Hor. Freq. Band 3
18		18	
19		19	Ver. Freq. Band 3
		20	
		21	Hor. Freq. Band 4
		22	
		23	Ver. Freq. Band 4
		24	
		25	Hor. Freq. Band 5
		26	
		27	Ver. Freq. Band 5
		28	
		29	Hor. Freq. Band 6
		30	
		31	Ver. Freq. Band 6
		32	
		33	

TABLE 2.6-3

"C" LOGIC RECORD GATES

(First 200 Ms of Pre-Test Period)

5-Level Character Printing		8-Level Character Printing	
Gate No.	Function	Gate No.	Function
C_1	Time (a)	C_1	Time (a)
2	Time (b)	2	Time (b)
3	Time (c)	3	Time (c)
4	Time (d)	4	Azimuth (a)
5	Azimuth (a)	5	Azimuth (b)
6	Azimuth (b)	6	Elevation (a)
7	Azimuth (c)	7	Elevation (b)
8		8	Range (a)
9	Elevation (a)	9	Range (b)
10	Elevation (b)	10	Hor. Freq. (a) Band 1
11	Elevation (c)	11	Hor. Freq. (b) Band 1
12		12	Ver. Freq. (a) Band 1
13	Range (a)	13	Ver. Freq. (b) Band 1
14	Range (b)	14	Hor. Freq. (a) Band 2
15	Range (c)	15	Hor. Freq. (b) Band 2
16		16	Ver. Freq. (a) Band 2
17	Hor. Freq. (a) Band 1	17	Ver. Freq. (b) Band 2
18	Hor. Freq. (b) Band 1	18	Hor. Freq. (a) Band 3
19	Hor. Freq. (c) Band 1	19	Hor. Freq. (b) Band 3
20		20	Ver. Freq. (a) Band 3
21	Ver. Freq. (a) Band 1	21	Ver. Freq. (b) Band 3
22	Ver. Freq. (b) Band 1	22	Hor. Freq. (a) Band 4
23	Ver. Freq. (c) Band 1	23	Hor. Freq. (b) Band 4
24		24	Ver. Freq. (a) Band 4
25	Hor. Freq. (a) Band 2	25	Ver. Freq. (b) Band 4
26	Hor. Freq. (b) Band 2	26	Hor. Freq. (a) Band 5
27	Hor. Freq. (c) Band 2	27	Hor. Freq. (b) Band 5
28		28	Ver. Freq. (a) Band 5
29	Ver. Freq. (a) Band 2	29	Ver. Freq. (b) Band 5
30	Ver. Freq. (b) Band 2	30	Hor. Freq. (a) Band 6
31	Ver. Freq. (c) Band 2	31	Hor. Freq. (b) Band 6
32		32	Ver. Freq. (a) Band 6
33	Hor. Freq. (a) Band 3	33	Ver. Freq. (b) Band 6
34	Hor. Freq. (b) Band 3		
35	Hor. Freq. (c) Band 3		
36			
37	Ver. Freq. (a) Band 3		
38	Ver. Freq. (b) Band 3		
39	Ver. Freq. (c) Band 3		
40			

TABLE 2.6-3

"C" LOGIC RECORD GATES (Cont'd)

(First 200 Ms of Pre-Test Period)

5-Level Character Printing		8-Level Character Printing	
Gate No.	Function	Gate No.	Function
C_{41}	Hor. Freq. (a) Band 4		
42	Hor. Freq. (b) Band 4		
43	Hor. Freq. (c) Band 4		
44			
45	Ver. Freq. (a) Band 4		
46	Ver. Freq. (b) Band 4		
47	Ver. Freq. (c) Band 4		
48			
49	Hor. Freq. (a) Band 5		
50	Hor. Freq. (b) Band 5		
51	Hor. Freq. (c) Band 5		
52			
53	Ver. Freq. (a) Band 5		
54	Ver. Freq. (b) Band 5		
55	Ver. Freq. (c) Band 5		
56			
57	Hor. Freq. (a) Band 6		
58	Hor. Freq. (b) Band 6		
59	Hor. Freq. (c) Band 6		
60			
61	Ver. Freq. (a) Band 6		
62	Ver. Freq. (b) Band 6		
63	Ver. Freq. (c) Band 6		
64			
65			
66			
67			
68			
69			
70			
71			
72			
73			
74			
75			
76			

TABLE 2.6-4

"B" LOGIC READ GATES

(First 200 Ms of Test Period)

5-Level Character Printing

Gate No.	Function
B_1	Time, Tracking & Altitude Data
2	
3	
4	
5	
6	
7	Hor. Signal Band 1
8	Ver. Signal Band 1
9	Hor. Signal Band 2
10	Ver. Signal Band 2
11	Hor. Signal Band 3
12	Ver. Signal Band 3
13	Hor. Signal Band 4
14	Ver. Signal Band 4
15	Hor. Signal Band 5
16	Ver. Signal Band 5
17	Hor. Signal Band 6
18	Ver. Signal Band 6
19	

8-Level Character Printing

Gate No.	Function
B_1	Time, Tracking & Altitude Data
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	Hor. Signal Band 1
17	Ver. Signal Band 1
18	Hor. Signal Band 2
19	Ver. Signal Band 2
20	Hor. Signal Band 3
21	Ver. Signal Band 3
22	Hor. Signal Band 4
23	Ver. Signal Band 4
24	Hor. Signal Band 5
25	Ver. Signal Band 5
26	Hor. Signal Band 6
27	Ver. Signal Band 6
28	
29	
30	
31	
32	
33	

TABLE 2.6-5

"C" LOGIC RECORD GATES

(First 200 Ms of Test Period)

5-Level Character Printing

Gate No.	Function
C_1	Time (a)
2	Time (b)
3	Time (c)
4	Time (d)
5	Azimuth (a)
6	Azimuth (b)
7	Azimuth (c)
8	
9	Elevation (a)
10	Elevation (b)
11	Elevation (c)
12	
13	Range (a)
14	Range (b)
15	Range (c)
16	
17	Heading (a)
18	Heading (b)
19	Heading (b)
20	
21	Pitch (a)
22	Pitch (b)
23	Pitch (c)
24	
25	Roll (a)
26	Roll (b)
27	Roll (c)
28	
29	Hor. Sig. (a) = $C_{29, 37, 45, 53, 61, 69}$
30	Hor. Sig. (b) = $C_{30, 38, 46, 54, 62, 70}$
31	
32	
33	Ver. Sig. (a) = $C_{33, 41, 49, 57, 65, 73}$
34	Ver. Sig. (b) = $C_{34, 42, 50, 58, 66, 74}$
35	
36	

8-Level Character Printing

Gate No.	Function
C_1	Time (a)
2	Time (b)
3	Time (c)
4	Azimuth (a)
5	Azimuth (b)
6	Elevation (a)
7	Elevation (b)
8	Range (a)
9	Range (b)
10	Heading (a)
11	Heading (b)
12	Pitch (a)
13	Pitch (b)
14	Roll (a)
15	Roll (b)
16	Hor. Sig. = $C_{16, 18, 20, 22, 24, 26}$
17	Ver. Sig. = $C_{17, 19, 21, 23, 25, 27}$
18	
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	
31	
32	
33	

TABLE 2.6-5

"C" LOGIC RECORD GATES (Cont'd)

(First 200 Ms of Test Period)

5-Level Character Printing		8-Level Character Printing	
Gate No.	Function	Gate No.	Function
C_{37}			
38			
39			
40			
41			
42			
43			
44			
45			
46			
47			
48			
49			
50			
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52			
53			
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76			

TABLE 2.6-6

"B" LOGIC READ GATES

(First 200 Ms of Second One Second Period of Post-Test Period)

5-Level Character Printing		8-Level Character Printing	
Gate No.	Function	Gate No.	Function
B_1	Time & Tracking Data	B_1	Time & Tracking Data
2		2	
3		3	
4	Sig. Calib. Band (n) = B_4 thru $_{13}$	4	
5		5	
6		6	
7		7	
8		8	
9		9	Hor. Sig. Calib. Band (n) = C_9 thru $_{18}$
10		10	
11		11	
12		12	
13		13	
14		14	
15		15	
16		16	
17		17	
18		18	
19		19	Ver. Sig. Calib. Band (n) = C_{19} thru $_{28}$
		20	
		21	
		22	
		23	
		24	
		25	
		26	
		27	
		28	
		29	
		30	
		31	
		32	
		33	

TABLE 2.6-7

"C" LOGIC RECORD GATES

(First 200 Ms of Second One Second Period of Post-Test Period)

5-Level Character Printing: Gate No.	5-Level Character Printing: Function	8-Level Character Printing: Gate No.	8-Level Character Printing: Function
C_1	Time (a)	C_1	Time (a)
2	Time (b)	2	Time (b)
3	Time (c)	3	Time (c)
4	Time (d)	4	Azimuth (a)
5	Azimuth (a)	5	Azimuth (b)
6	Azimuth (b)	6	Elevation (a)
7	Azimuth (c)	7	Elevation (b)
8		8	Range (a)
9	Elevation (a)	9	Range (b)
10	Elevation (b)	10	Hor. Sig. Calib. Band (n) $= C_{10 \text{ thru } 19}$
11	Elevation (c)	11	
12		12	
13	Range (a)	13	
14	Range (b)	14	
15	Range (c)	15	
16		16	
17	Sig. Calib. (a) Band (n) $= C_{17,21,25,29,33,37,41,45,49,53}$	17	
18		18	
19		19	
20		20	
21		21	Ver. Sig. Calib. Band (n) $= C_{20 \text{ thru } 29}$
22	Sig. Calib. (b) Band (n) $= C_{18,22,26,30,34,38,42,46,50,54}$	22	
23		23	
24		24	
25		25	
26		26	
27		27	
28		28	
29		29	
30		30	
31		31	
32		32	
33		33	
34			
35			
36			

TABLE 2.6-7

"C" LOGIC RECORD GATES (Cont'd)

(First 200 Ms of Second One Second Period of Post-Test Period)

5-Level Character Printing		8-Level Character Printing	
Gate No.	Function	Gate No.	Function
C37			
38			
39			
40			
41			
42			
43			
44			
45			
46			
47			
48			
49			
50			
51			
52			
53			
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TABLE 2.6-8 "A" LOGIC GATES

Gate No.	Logic Equation	Recorded Data: Time	Azimuth	Elevation	Range	Heading	Pitch	Roll	Hor. Signal	Ver. Signal	Hor. Freq.	Ver. Freq.	Hor. Calib.	Ver. Calib.	Period	Character Level: 5	8
A_1	A_1^1	x	x	x							x	x			Pre-test	x	x
A_2	A_2^1	x	x	x	x	x	x	x	x	x					Test	x	x
A_3	$A_3^1 D_1$	x	x	x	x						x	x			Post-test	x	x
A_4	$A_3^1 D_2$	x	x	x	x								x	x	Post-test	x	x
A_5	$A_3^1 D_3$	x	x	x	x								x	x	Post-test	x	x
A_6	$A_3^1 D_4$	x	x	x	x								x	x	Post-test	x	x
A_7	$A_3^1 D_5$	x	x	x	x								x	x	Post-test		
A_8	$A_4^1 D_1$	x	x	x	x								x	x	Post-test		
A_9	$A_4^1 D_2$	x	x	x	x								x	x	Post-test	x	x
A_{10}	$A_4^1 D_3$	x	x	x	x								x	x	Post-test	x	
A_{11}	$A_4^1 D_4$	x	x	x	x								x	x	Post-test	x	
A_{12}	$A_4^1 D_5$	x	x	x	x								x	x	Post-test	x	
A_{13}	$A_5^1 D_1$	x	x	x	x								x	x	Post-test	x	
A_{14}	$A_5^1 D_2$	x	x	x	x								x	x	Post-test	x	
A_{15}	$A_5^1 D_3$	x	x	x	x								x	x	Post-test	x	

is utilized to simultaneously transfer, in parallel, all data pertinent to aircraft position and attitude in accordance with the recording format. Other "B" gates are used to commutate the analog input data.

"C" gates are provided for the specific purpose of controlling the recording of digitized data. Inasmuch as the digitized data contains a minimum of 8 to 14 binary bits, one or more characters will be required per parameter. For convenience, the number of "C" gates will be a multiple of the number of "B" gates. In the systems considered, it will be noted that 76 "C" gates are required for a 5-level character recording; whereas 33 "C" gates are required for the 8-level character recording. In the 8-level system, the "B" and "C" gates are identical and are derived from a common gate generator. Consequently, the maximum recording rates will be 380 and 165 characters per second for the 5- and 8-level recording, respectively.

The above recording rates clearly preclude the use of standard punched tape recorders which operate at typical rates of 60 characters per second. State of the art of electrostatic recording techniques permits recording rates from 300 to 1000 characters per second. However, it should be noted that special readers are required to communicate to the computer.

2.6.2.1 Controller. - The controller block diagram shown in Fig. 2.6-4 is comprised of a series of counters interconnected to provide the various read and record gates. The array of counters is driven by the controller clock, which is synchronized with the AN/USQ-23V digital time system. The design of the controller is based upon the choice of an 8-level character recording which will permit an expansion in data rate beyond that of the 5-level character.

The minimum clock rate is uniquely determined by the maximum number of bits contained in digitized analog data and the number of "B" gates. For the system under consideration, the clock rate would be 1980 pulses per second. The internal clock pulses are gated into the controller input via a start-stop gate which will be enabled by a signal from the tracking system signifying the start of the data run. Similarly, the gate will revert to its open position at the end of the data run.

The maximum word length from the analog-to-digital converter is 12 binary bits which is determined by the scale-of-12 counter which is driven at the clock rate of 1980 pps. Similarly, the character length is determined by a scale-of-8 counter.

"B" gates are generated by combining outputs from each stage of a 6-stage counter in "And" logic circuits. Feedback from the last stage (2^5) is applied to each of the other stages to form a scale-of-33 counter. The net result is a commutator having 33 segments each having a duration of 12 clock pulses.

As will be noted by the logic equations listed in Table 2.6-9, "C" logic is identical to that of "B" by virtue of their one-to-one association.

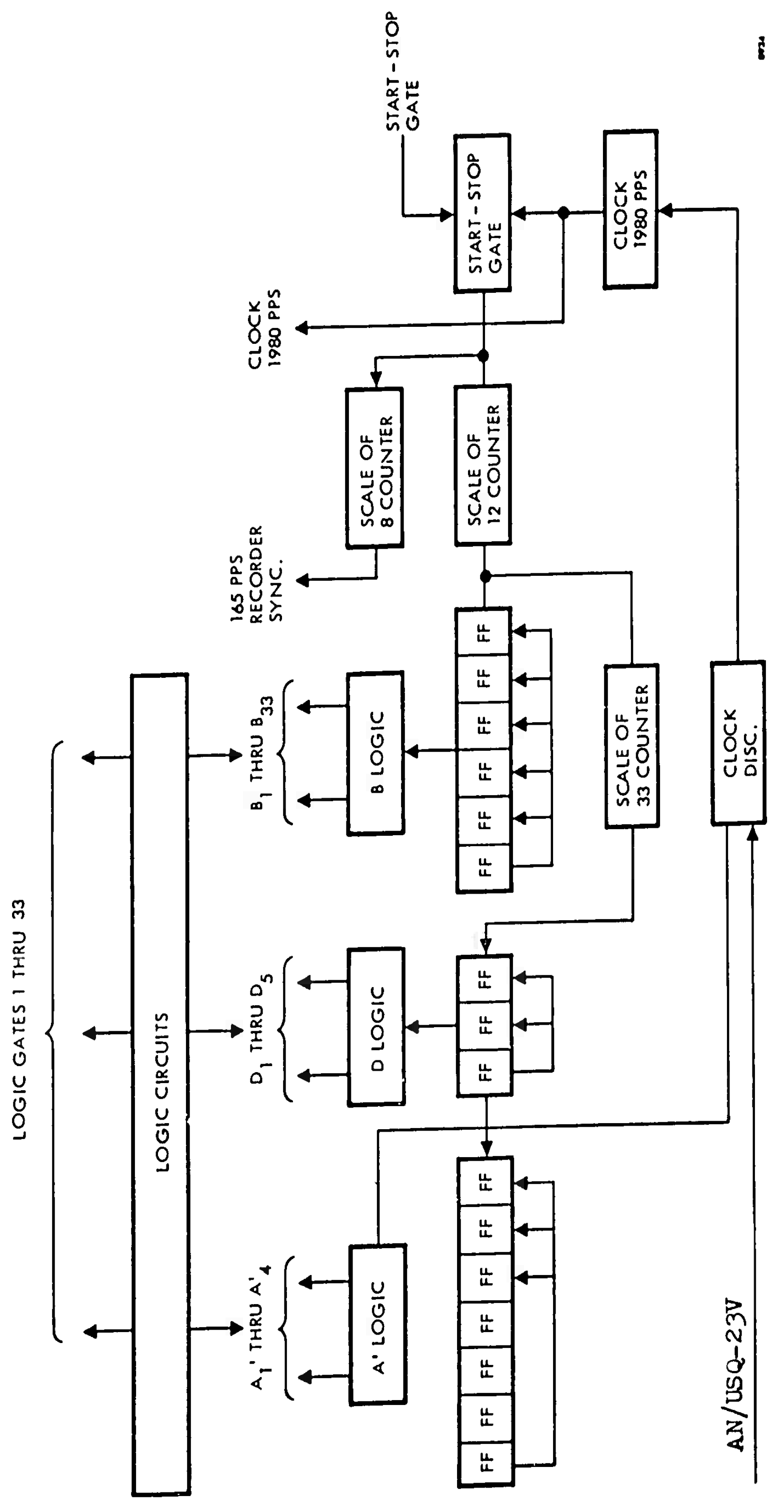


Figure 2.6-4. Controller Block Diagram

TABLE 2.6-9

LOGIC EQUATIONS

Read Analog Gating Data	Logic Equation	Logic Gate No.
Hor. Sig. Band 1	$A_2\ B_7 + A_4\ (B_9 + B_{10} + \ldots B_{18})$	1
Ver. Sig. Band 1	$A_2\ B_8 + A_4\ (B_{19} + B_{20} + \ldots B_{28})$	2
Hor. Freq. Band 1	$D_1\ (A_1\ B_4 + A_3\ B_9)$	3
Ver. Freq. Band 1	$D_1\ (A_1\ B_5 + A_3\ B_{11})$	4
Hor. Sig. Band 2	$A_2\ B_9 + A_5\ (B_9 + B_{10} - \ldots B_{18})$	5
Ver. Sig. Band 2	$A_2\ B_{10} + A_5\ (B_{19} + B_{20} + \ldots B_{28})$	6
Hor. Freq. Band 2	$D_1 (A_1\ B_6 + A_3\ B_{13})$	7
Ver. Freq. Band 2	$D_1\ (A_1\ B_7 + A_3\ B_{15})$	8
Hor. Sig. Band 3	$A_2\ B_{11} + A_6\ (B_9 + B_{10} + \ldots B_{18})$	9
Ver. Sig. Band 3	$A_2\ B_{12} + A_6\ (B_{19} + B_{20} + \ldots B_{28})$	10
Hor. Freq. Band 3	$D_1\ (A_1\ B_8 + A_3\ B_{17})$	11
Ver. Freq. Band 3	$D_1\ (A_1\ B_9 + A_3\ B_{19})$	12
Hor. Sig. Band 4	$A_2\ B_{13} + A_7\ (B_9 + B_{10} + \ldots B_{18})$	13
Ver. Sig. Band 4	$A_2\ B_{14} + A_7\ (B_{19} + B_{20} + \ldots B_{28})$	14
Hor. Freq. Band 4	$D_1\ (A_1\ B_{10} + A_3\ B_{21})$	15
Ver. Freq. Band 4	$D_1\ (A_1\ B_{11} + A_3\ B_{23})$	16
Hor. Sig. Band 5	$A_2\ B_{15} + A_8\ (B_9 + B_{10} + \ldots B_{18})$	17
Ver. Sig. Band 5	$A_2\ B_{16} + A_8\ (B_{19} + B_{20} + \ldots B_{28})$	18
Hor. Freq. Band 5	$D_1\ (A_1\ B_{12} + A_3\ B_{25})$	19
Ver. Freq. Band 5	$D_1\ (A_1\ B_{13} + A_3\ B_{27})$	20
Hor. Sig. Band 6	$A_2\ B_{17} + A_9\ (B_9 + B_{10} + \ldots B_{18})$	21
Ver. Sig. Band 6	$A_2\ B_{19} + A_9\ (B_{19} + B_{20} + \ldots B_{28})$	22
Hor. Freq. Band 6	$D_1\ (A_1\ B_{14} + A_3\ B_{29})$	23
Ver. Freq. Band 6	$D_1\ (A_1\ B_{15} + A_3\ B_{31})$	24
Signal	$A_2\ (C_{16} + C_{17} + \ldots C_{27})$ $+ (A_4 + A_5 + A_6 + \ldots A_9)$ $(C_{10} + C_{11} \ldots C_{29})$	25

TABLE 2.6-9

LOGIC EQUATIONS (Cont'd)

Read Digital Gating	Logic Equation	Logic Gate No.
Time	$B_1 \ D_1$	26
Azimuth	B_1	27
Elevation	B_1	27
Range	B_1	27
Heading	$A_2 \ B_1$	28
Pitch	$A_2 \ B_1$	28
Roll	$A_2 \ B_1$	28
Record Digital Gating		
Time (a)	$D_1 \ C_1 = D_1 \ B_1$	26
Time (b)	$D_1 \ C_2 = D_1 \ B_2$	29
Time (c)	$D_1 \ C_3 = D_1 \ B_3$	30
Azimuth (a)	$C_4 = B_4$	31
Azimuth (b)	$C_5 = B_5$	32
Elevation (a)	$C_6 = B_6$	33
Elevation (b)	$C_7 = B_7$	34
Range (a)	$C_8 = B_8$	35
Range (b)	$C_9 = B_9$	36
Heading (a)	$A_2 \ C_{10} = A_2 \ B_{10}$	37
Heading (b)	$A_2 \ C_{11} = A_2 \ B_{11}$	38
Pitch (a)	$A_2 \ C_{12} = A_2 \ B_{12}$	39
Pitch (b)	$A_2 \ C_{13} = A_2 \ B_{13}$	40
Roll (a)	$A_2 \ C_{14} = A_2 \ B_{14}$	41
Roll (b)	$A_2 \ C_{15} = A_2 \ B_{15}$	42

Inasmuch as there will be 5 groups of "B" gates per second, "D" gates each having a duration of 200 milliseconds or 396 clock pulses are generated by dividing the output from the scale-of-12 counter by a scale-of-33 counter similar to the one used for "B"-gate generation. The output from the scale-of-33 counter is used to drive a scale-of-5 counter, each stage of which is connected through "And" logic circuits to generate each of the five "D" gates.

Similarly, "A" gates are generated by means of interconnecting the individual stages of a scale-of-121 counter through "And" logic. Each of the 121 gates are of 1-second duration.

To insure synchronization of the internal clock with the 1-pps synchronization pulse from the AN/USQ-23V digital timing system, an automatic frequency-control loop is required. The AFC action is readily accomplished by comparing the one-second periods from one of the "A" gates with that of the AN/USQ-23V. The resulting error signal will be used to adjust the internal clock to the proper rate.

Inasmuch as the controller can provide gates having periods of 1/165 secs, 1/5 sec, and 1 sec duration, it is possible through logic circuits to select any 1/165-sec gate within the entire data run of 121 seconds. Consequently, any format of reading in or recording of any particular parameter can be programmed by solving the indicated logical equations. Such a design permits a means of programming the controller in accordance with a particular flow of data associated with various flight patterns.

2.6.3 <u>On-Line Data Processor</u>. - A study of a processor employing a computer <u>on-line</u> indicates that there are numerous advantages over one which only gathers data for later reduction by a remote computer facility. As was mentioned earlier, the use of a computer to reduce the data as it is acquired can provide an optimum utilization of aircraft time. Thestudy also indicates that it is feasible and practical to consider the use of the computer to perform other than computational duties and thereby effect a reduction in system costs.

A survey of available computers indicates that the AN/UYK-1 Digital Computer is an optimum choice in that it is a rugged militarized computer that has the capacity and flexibility to gather and process data on a real-time basis at rates well in excess of the immediate requirements on the AN/MSQ-16 complex. The capacity of the computer is such that continuous data may be processed during actual flight operations.

Areas of interest investigated in the study of on-line integration of the digital computer were:

a. man-machine communication

b. problem adaptability

c. system flexibility

d. quasi-real time results

e. economics

f. reliability

g. expandability

During complex operations there is generally a requirement to modify problem parameters or introduce additional parameters into the problem. There may also be a requirement for the visual observance of specific data being transferred to the computer and/or there may be a need to observe the final computed results of a particular operation. All these requirements can be satisfied by the man-machine communication that is provided through the medium of the peripheral typewriter associated with the computer system. The typewriter obviates the need of a special console with complicated displays and control. Monitoringof the value of a particular function is affected by a request transferred to the computer by means of the typewriter. Pertinent operations data may also be transferred to the computer for storage with the operational results.

As often happens during complex operations, there occassionally arises the requirement to vary the data word length, the data scan rates or to modify the data format and the sequence of sampling. These variations usually necessitate a period of equipment modification, raising the question of equipment reliability for future operations. Operations having identical requirements must therefore be carefully planned to occur during the same period to prevent reverting to a previously utilized equipment modification.

A digital computer on-site will accommodate changing operational requirements such as varying data formats, word size, variable data scan rate, data function ordering, and changing mathematical computational tasks, all without system redesign.

The computer operational program can provide the necessary command signals for random selection of digital function data available in registers of the AN/MSQ-16 complex. In addition commands can also provide the ordering of analog data by random addressing of the data multiplexer in the AN/MSQ-16 equipment. Thus, it becomes a matter of introducing a previously utilized operational program to repeat a previous phase of the operation.

The selection of a code for use with the data processor has been considered and was discussed in earlier paragraphs. The selection of a code for use with the on-line digital computer is not as restrictive as with a wired data processor, since the on-line digital computer has the flexibility to accept a variety of digital codes and can readily perform the conversion to a binary code. Digital codes, however, require different computer time to perform the conversion and will affect computer utilization if the computer workload is great. The grey code requires the least conversion time and therefore is preferred even though computer utilization does not present a problem in the present system concept.

The system may be readily expanded to accommodate growing problem requirements. Ample computational capacity remains in the computer and is available for accommodating larger programs. The recording device, the paper tape punch, is the device that currently limits the system's growth.

Should the available time for recording on paper tape between test runs become insufficient, then the system may be expanded to include one or more magnetic tape recording devices recording operational data at character rates of 15,000 to 41,700 characters per second and in an IBM compatible format.

The on-line computer system may be expanded effectively to vector the aircraft during critical test requirements through a fixed point in space maintaining the correct heading throughout, thereby obviating the possibility of an abort due to voice communication delays and errors between air controllers and the aircraft pilot.

The computer selected for the on-line application is the AN/UYK-1 Digital Computer. The AN/UYK-1 is a proven, reliable, solid state MIL-Spec computer. The average MTBF of the computer in the field under actual operating conditions has surpassed 1000 hours.

The Digital Interface Buffer will be designed and fabricated using the same proven, reliable techniques and modules as utilized in the AN/UYK-1 computer system.

One very important consideration in any system is the economics involved in major system implementation. Flexible, expandable, off-the-shelf equipment with proven reliability, coupled with interface equipment designed and fabricated of computer type modules requires a minimal R&D effort as compared to a special-purpose programmer-recorder. The flexible digital computer system remains intact and may be integrated into other systems or assigned other tasks, extending its span of usefulness beyond its use in its present assignment. The special-purpose device, however, cannot serve other functions unless it undergoes major modifications.

The foregoing section has detailed the many features and major advantages to be obtained by implementing an on-line digital computer system with the Data Acquisition System. Briefly, these features and advantages are:

a. A processor on site will accommodate varying operational requirements, such as varying data formats, word size, mathematical computations required and variable data scan rates without system redesign, thus providing almost unlimited flexibility.

b. The subsystem provides random selection, under computer operational program control, of digital and analog data.

c. A processor on site will provide quasi-real-time results whereby immediate evaluation of test runs may be made by the operator. Test runs may be repeated during the same operational period with the resultant economy of eliminating repeat operations at a future date.

d. Man-machine communication is provided through the medium of the typewriter. Test-run evaluation results and other operator comments may be transferred to the computer core memory for subsequent recording with the data. Also, test data may be ordered to be displayed on the typewriter as a visual monitor. The typewriter is a standard peripheral equipment, thereby obviating the need of a special console with complicated displays.

e. Test results may be recorded on the digital plotter in quasi-real-time, thereby providing immediate evaluation and/or final product (antenna radiation pattern).

f. Code conversion is conveniently and efficiently implemented by means of the computer operational program eliminating the requirement for additional system hardware.

g. The AN/UYK-1 is a proven, reliable MIL-Spec computer, and has been delivered and accepted in a wide range of programs. The AN/UYK-1 has been issued a Federal Stock Number, and all standard peripheral equipments have been issued Federal Stock Numbers.

h. The Digital Interface Buffer will be designed and fabricated using proven, reliable techniques and modules used in the computer system.

The use of standard modules reduces the spares provisioning requirements of the system. All parts are listed on the Federal Supply Schedule.

i. A processor on site may also be programmed to effectively vector the aircraft during critical test requirements through a fixed point in space maintaining the correct heading throughout.

j. The subsystem may be expanded to accommodate higher data processing rates without physical modification to the original system.

2.7 CONTROLS AND DISPLAYS

This section discusses the configuration of the Control Console necessary to provide at a central point all the man/machine interface functions required. Topics discussed include communications, data entry, system monitoring, and displays.

2.7.1 Communications Considerations. - Communication Links from the ground to air and air to ground are vital to the operation of the AN/MSQ-16 system. It is required to issue flight directions to the pilot in order to bring the aircraft to a designated position before an approach is made to the intercept point. At prescribed time intervals signals are sent to the pilot to instruct him to properly orient the aircraft for data measurements. Such data, as well as navigational information, can be adequately handled by voice communications. Existing communications equipment presently installed in the aircraft can be located in the AN/MSQ-16 to perform this function.

The Control Central Console will have a microphone and a mike foot bar switch and other communications control features that will allow the control operator to communicate with the aircraft as needed. Intercommunications with the radar tracking facilities will keep the control central informed as to tracking progress. The radar tracking center will have the primary communications link with the aircraft since its responsibility is to direct the aircraft for preparation to make its run on the intercept point. Thus, the radar tracking facility of the AN/MSQ-16 must contain the flight control function, with its communications link. The control central will also have the capability of communicating with the pilot as well as monitoring communications between the pilot and the radar tracking central control center. The control central console will be provided with intercommunications with the radar tracking center. Voice channels will also be available for communication with aircraft and for monitoring of the aircraft tracking center channels as well. The control central can use the same transmitting and receiving equipment as the radar tracking center, or separate equipment, if available.

2.7.2 Data-Entry Techniques. - The primary function of the AN/MSQ-16 is the collection of data for the purpose of plotting an airborne antenna pattern. Data is received for processing by several different sources and the method of entry is either automatic or manual, depending on the data source and sample rate. Those signals which are automatically measured are automatically entered into the system, while those signals which are not measured by data processing equipment of the AN/MSQ-16 are entered manually. Automatic entry has been discussed in detail in Sec. 2.6 (Data Processing), whereas manual entry at the control display console is discussed in this section.

The data to be entered into the data processing system is listed in Table 2.7-1, indicating the method of entry (Manual or Automatic) and whether the data applies to a specific channel ("Channel") or equally to all channels monitored during the run ("Run"). Each entry item will have a dynamic range over which it may vary; the third column provided in Table 2.7-1 shows the decimal digit range covering the corresponding variation.

All manual entries are made at the control monitor panel of the control central console. Various means for entering these data have been considered. Among these methods was the placing of standard data-entry words on front-panel switch keys which may be depressed manually when the corresponding word is to be entered. The worded switches would be supplemented by a numerical key set group so that the magnitude corresponding to the word may be punched and entered into the system simultaneously. For example, when frequency is entered, the button marked "frequency" is depressed and then the numerical frequency is punched in to the key set. Finally, the "data entry" button is depressed, causing the frequency punched out on the key set to be entered into the data processing system and clearing the data entry switches for another operation.

Another method that can be employed with an on-line computer in the system, is to enter the data with the same typewriter that is normally used to communicate with the computer system. Since the typewriter and the computer are designed to operate together there would be no design effort necessary to implement this particular technique. Thus, this particular method offers an economical means of data entry into the system.

TABLE 2.7-1

DATA ENTRY INFORMATION

Type Data	Type Entry	Channel or Run	Range Decimal Digits
Type Signal	Manual	Channel	1
IF Bandwidth	Manual	Channel	1
Frequency	Manual	Channel	5
Data Quality	Manual	Channel	1
*Roll (Aircraft)	Manual	Run	4
*Pitch (Aircraft)	Manual	Run	4
*Heading (Aircraft)	Manual	Run	4
Test Number	Manual	Run	5
Date	Manual	Run	4
Weather	Manual	Run	6
Signal Level (Vert.)	Auto.	Channel	2
Signal Level (Horz.)	Auto.	Channel	2
Frequency	Auto.	Channel	3
Azimuth	Auto.	Run	4
Elevation	Auto.	Run	4
Range	Auto.	Run	4

*These data are assumed to be constants of known value in the absence of an air-to-ground data link.

Another method that could be used would involve a control panel which had only a key set and a data entry button. Information could be entered by manually setting up a code that would correspond to each type of word to be entered into the system. This scheme would operate as follows: If one wished to enter frequency into the system, a code chart would be consulted that would designate the code for frequency, such as word No. 2, for example. The operator would then punch No. 2 and the data entry button, entering the word into the system. Then the magnitude of the frequency would be punched on the key set and likewise entered into the system. This scheme would be more economical than the scheme whereby the words are called out on separate buttons, but it would be somewhat difficult and clumsy to utilize, since the time consumed in looking up data codes would be excessive when the operator wanted to enter data rapidly. This method could be u-ed for entering additional words in a future expansion, however, since the key set in the original system will already be available.

2.7.3 System Monitoring Requirements. - Since it is desirable for the proper operation of the system that the various signals pertinent to data processing be checked, monitoring of the manual-entry keyboard signals is an important function of the central control console operator position. Signals that should be monitored include vertical signal strength, horizontal signal strength, elevation, range, azimuth, and frequency. The vertical signal, horizontal signal and frequency would have different values for each individual channel, while the range, elevation, and azimuth angles would be common to all data channels. The control console operator should also be able to monitor the radar tracking function to the degree of knowing whether the radar is tracking and when the track has been dropped. It should also be known whether the radar is being used or whether the passive tracking of the AN/MSQ-16 is performing the tracking function.

As was tabulated in Table 2.7-1, the highest range covered by the various signals was six decimal digits. Because of this it is recommended that the monitor control panel possess the capability of displaying six decimal digits in large clear legible numerals on the front panel. Since the data is entered in decimal-coded format and is converted to binary, it is further recommended that, along with the decimal numerals, indication be provided to show the binary code corresponding to the decimal numerals. The numerical Display should be of the projection type with a minimum numeral height of one inch.

Since frequency drift is an important function to be monitored while making pattern measurements, means should be provided for knowing whether or not the frequency has drifted beyond specific limits. The frequency would be monitored automatically by a discriminator circuit; when the frequency excursion exceeded a desired tolerance value, an alarm light would show on the front panel, designating the channel number where the drift had occurred. The operator could then readjust the receiver of that particular signal to bring it on frequency or could alert the aircraft as to the frequency drift problem.

A clock of the type AN/USQ-23V would also be included on the monitor panel giving the operator a read-out of time for use in the system.

When a signal is to be monitored, the operator would select a button displaying the corresponding word and then press the channel button corresponding to the signal for that particular channel. This method would be both simple and economical to implement.

As in the case of the control function, the monitor function could be performed by typing into the typewriter the signals to be monitored. The computer would then type out automatically the desired data to be monitored. An advantage of this method would be that several signals could be monitored on a continuous basis. In other words, the typewriter could type out, say, three columns-vertical signal, horizontal signal, and range to the target. Or it could type out columns designating how various signals are received. One disadvantage of this method would be the small time delay between the signal reception, processing, and typing out on the typewriter.

2.7.4 Panoramic Displays. - In order to provide the capability for spectrum signature measurements and to ease the frequency location and identification of signals, the AN/MSQ-16 should be equipped with panoramic displays. The panoramic displays will provide a graphic indication of frequency vs. signal amplitude and can provide significant data as to the received signal frequency spectrum. This in turn can be interpreted to provide information as to the characteristics of the signal modulation.

It is presently envisioned that two panoramic display configurations will be required for the AN/MSQ-16. These correspond to the two basic modes of receiver operation, i.e., broadband scanning of the receiver's first local oscillator and fixed tuned operation. The first mode of operation can provide a broad view of the entire receiver's tuning range or any selectable portion. However, during fixed frequency operation it is still desirable to monitor the received signal spectrum, primarily to insure that the signal frequency is centered within the receiver i-f pass-band. This second panoramic display can be obtained during fixed frequency operation by employing a double conversion receiver, and sweeping the second L.O. followed by a narrow bandwidth i-f amplifier and detector. This provides a panoramic display which will display an r-f band equal to the first i-f bandwidth, centered at the frequency at which the receiver is tuned. It is desirable that this first r-f bandwidth be wide enough to provide a maximum display width of between 10 Mc and 20 Mc.

Of prime interest, when considering the use of panoramic displays, are the range of sweep speeds required, the i-f bandwidth employed and the method of signal amplitude control.

In the case of continuous signals either AM or FM modulated, the parameters of the panoramic receiver and display must meet two criteria. First, in order to display the modulation side bands, the receiver resolution must be equal or better than the modulation frequencies. The frequency resolution of the panoramic receiver is essentially equal to its i-f bandwidth before detection. Secondly, the receiver must not scan so fast past the signal that the receiver i-f does not have time to respond. This requirement is a function of the scan rate and i-f bandwidth and can be expressed by the following:

$$\frac{B^2}{\Delta F f_s} \geq 1 \qquad (2.7\text{-}1)$$

where:

B = the i-f bandwidth

ΔF = the width of the r-f band being scanned

f_s = the frequency at which the r-f band is scanned.

This limitation is not serious for reasonable values of i-f bandwidth B. As an example, if B = 1 Mc, F = 2,000 Mc, the maximum frequency at which the band could be scanned to display continuous signals would be 500 cps. However, if B were reduced to 25 Kc, f_s would have to be reduced to 0.3 cps.

In the case of the narrow band panoramic receiver and display, the i-f bandwidth can be narrowed considerably to provide increased resolution. For ΔF = 20 Mc, B = 25 Kc, f_s could be as high as 30 cps, which would provide a good display.

The situation for pulse type signals is somewhat different. In order to provide an acceptable display, the time it takes the receiver to scan through the signal spectrum width should allow enough signal returns to adequately define the signal spectrum. This assumes no scan-to-scan integration on the face of the CRT indicator, which is generally true for even relatively long decaying phosphors.

If the criterion is established such that at least 10 signal returns should be contained within $1/2\tau$ of the spectrum width, where τ is the pulse width, the following relation applies for determination of the maximum allowable frequency scan rate.

$$f_s < \frac{PRF}{20\,\tau\,\Delta F} \qquad (2.7\text{-}2)$$

where:

PRF = pulse repetition frequency

τ = pulse width.

An examination of this relation indicates that very slow scan speeds are required to meet the assumed criterion for low signal PRF's, wide pulse widths and a wide frequency scan width, as would be employed in the wide band panoramic configuration.

However, it can be expected that for this situation, i.e., wide frequency scan widths, almost perfect integration of the signal returns will be obtained on the indicator, so that the requirement for 10 returns can be relaxed, particularly if the signal-to-noise ratio is high. One could consider the use of more complicated means for scan to scan integration, such as the falling raster storage tube display. However, it is felt that this complication is not warranted for the AN/MSQ-16 system.

An additional consideration in a panoramic receiving system is the requirement that the system be capable of displaying a wide dynamic range of signal levels without overload. Limiting of the signal will cause the generation of spurious signal frequencies. Additionally, high signal levels at the mixers will cause signal responses at sub-harmonics and harmonics of the receiver i-f frequency, relative to the true signal frequency.

In the AN/MSQ-16 system, it is required that the receivers be capable of proper operation at signal levels of up to -10 dbm, referred to the antenna terminals. This high a signal level can cause possible overload problems, particularly with r-f pre-amplification. This difficulty can be overcome by the use of a pseudo instantaneous gain control applied to the r-f pre-amplifier. This scheme applies a gain control signal to the pre-amplifier, when the signal exceeds a fixed level, to reduce the gain by a fixed factor, typically on the order of 30 db. This allows the receiver dynamic range to be utilized over two ranges of input signal level. In addition, the receiver dynamic range must be extended over that obtainable with a linear receiver. This can be accomplished by the use of a logarithmic amplitude characteristic in the receiver i-f amplifier to compress the range of input signal level. A lin-log characteristic over a signal amplitude range of 60 db can easily be achieved, and this in conjunction with the pre-amplifier gain control will provide the display of signals with a 90-db variation in amplitude.

In summary, it can be concluded that for the wide band panoramic system, scan speeds between 0.1 cps and 30 cps should be provided, with the capability of scanning any portion of a particular band. An i-f bandwidth of 1.5 Mc will be adequate. The wide band panoramic system must include means for compressing a wide dynamic range of signal levels (0 to -90 dbm) to a range of 10:1 for display. The narrow band panoramic system has less requirements in that the signal levels will be of fixed amplitude and the scanning bandwidth is relatively narrow. An adjusted scan rate between 1 cps and 30 cps will provide for all expected signal parameters.

SECTION 3

OPERATIONAL CONSIDERATIONS

This section discusses those aspects of system operation which result from unavoidable characteristics of the environment as related to the system parameters. Topics discussed are aircraft flight patterns, system operating requirements, system siting, and antenna collimation.

3.1 AIRCRAFT FLIGHT PATTERNS AND FLIGHT PROCEDURES

There are several different types of flight test patterns which warrant consideration; each has unique advantages. However, before considering the relative merits of the various flight patterns that can be flown, the basic aircraft antenna pattern requirements have to be established.

The intended antenna mission, be it communications, electronic countermeasures, IFF, or navigation, will dictate to a great extent the maximum and minimum depression angles of interest. The depression angle increments must then be selected to insure adequate data to generate a representative plot. Extending the pattern depression angles, or selecting excessively fine increments adds flight time and computer time with little improvement in the value of the overall data.

3.1.1 Flight Patterns. - The fundamental flight pattern that has been used in the past is the so-called "Clover Leaf." In this method, the pilot is instructed to fly through an identification point (IP) at several predetermined azimuth angles, and at predetermined altitudes. Various IP's and altitudes can be selected and categorized by characteristic depression angles with respect to the horizontal plane passing through the test aircraft. Incremental azimuth aspect angle data can then be selected for each depression angle, with the resulting data being that which is required to describe the pattern of the antenna of interest.

Throughout the flight, the aircraft is under close control through a precision ground-based tracking radar. A control operator vectors the aircraft by instructing the pilot as to what headings to hold. Corrections are made to keep the aircraft on the proper flight path that will intercept the IP at the prescribed heading. Figure 3.1-1 shows a typical flight pattern. The aircraft approaches the IP and is aligned to the correct path by verbal instructions from the controller by means of the tracking radar. The pilot is given a verbal notification when the aircraft is one minute from the IP, over the IP, and one minute past the IP. At the first signal the pilot engages the autopilot to hold the aircraft straight and level until the notification that the post-IP minute has elapsed. He is then vectored to a new path over the IP. Obviously, a large part of the success of the mission is dependent upon

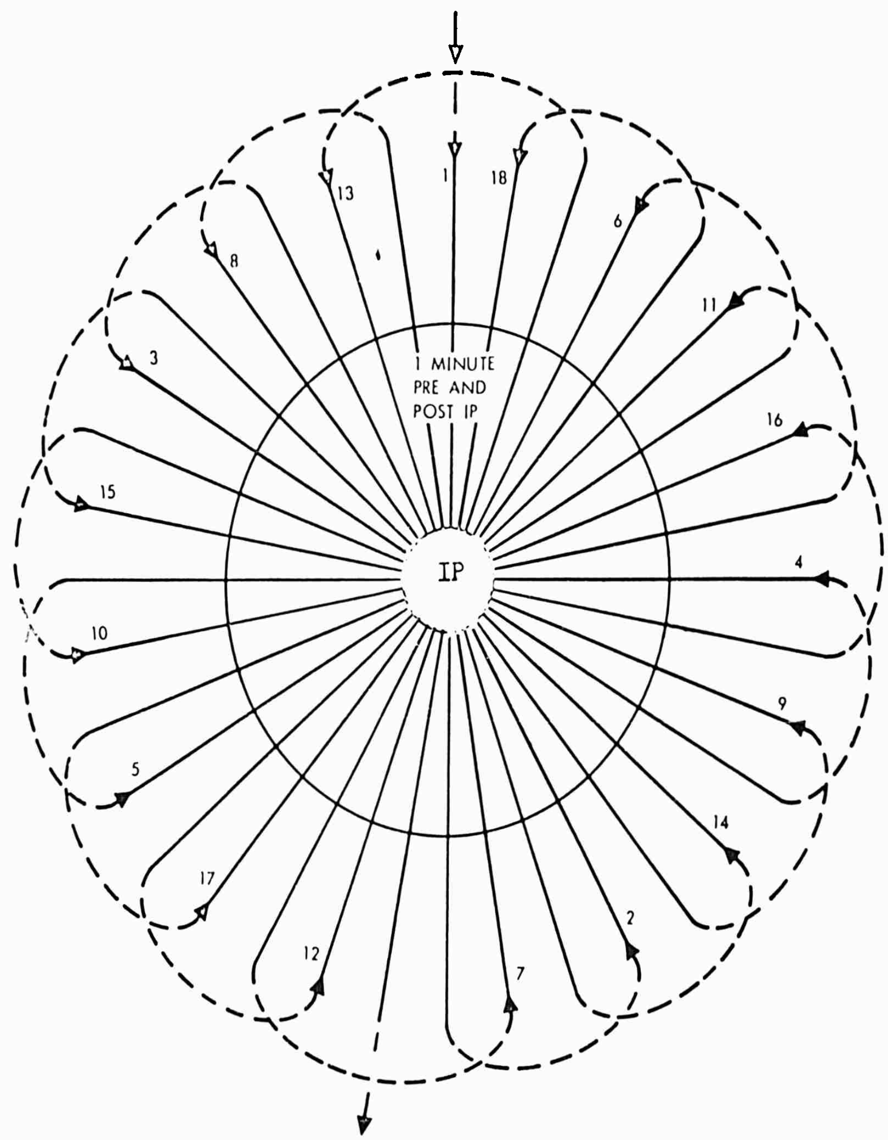


Figure 3.1-1. Typical Flight Plan for Cloverleaf Pattern

the skills of both the pilot and the controller. The close monitoring by the ground control operator permits determining whether each run is valid, and gives the opportunity of repeating immediately any invalid or doubtful runs.

A simple radar overlay would be applicable for any altitude or range; however, the required aspect angle increments would require separate overlays, and the flight path must be flown in both directions.

The total flight time for any one depression-angle cut would be approximately five hours, based upon 10° aspect angle increments. The flight time requirement per pattern varies directly with the number of data points that are required, insuring a minimum of flight time expenditure for a given volume of data.

Another possible flight pattern consists of a series of parallel flights flown at a constant altitude. This method enables obtaining a much larger number of data points per hour of flight time; however the entire pattern must be flown before sufficient data is available for any two-dimensional antenna pattern plot. Figure 3.1-2 represents a typical flight path. In this flight the aspect angle varies continuously from 30° to 150°; however, the depression angle also varies continuously. An altitude of 20,000 ft results in a depression angle range of approximately 4.8 degrees at 30° and 150° to a maximum of 9.5 degrees at a 90° aspect angle. In order to determine the number of flights and the extent of each pass a computer program would be written. This program would calculate the depression and aspect angles obtained along a series of parallel flight paths. An initial path spacing is selected, for example, one mile, and the resultant paths are plotted in a density diagram of aspect angle versus depression angle. The above procedures were discussed in a report entitled "Proposed methods for obtaining three dimensional Airborne Antenna Patterns on antennas installed on RADC's JKC-135 aircraft," written by Lt. Martin L. Young.

3.1.2 Dependence of Data on Flight Conditions. - The basic assumption of the test procedure, namely that the depression angle of any portion of the antenna pattern of a fixed antenna on an aircraft can be derived by ground tracking measurements, contains the implication that the longitudinal axis of the aircraft bears a constant relationship to the horizontal, specifically zero pitch angle. In fact, this assumption is incorrect, since the angle of attack of any fixed-wing aircraft varies approximately inversely as the square of airspeed for a given gross weight, and varies approximately as the square root of weight for any given airspeed. Since the available range of both parameters is large, the actual angle of attack in level flight (pitch angle) may have a variation of as much as ten degrees or more in typical airplanes. Since any variation in pitch angle directly affects the assumed angle of depression, it is necessary to use flight procedures which will either (1) result in a standard angle of attack throughout the flight, or (2) permit an angle of attack correction to be applied to the computed data.

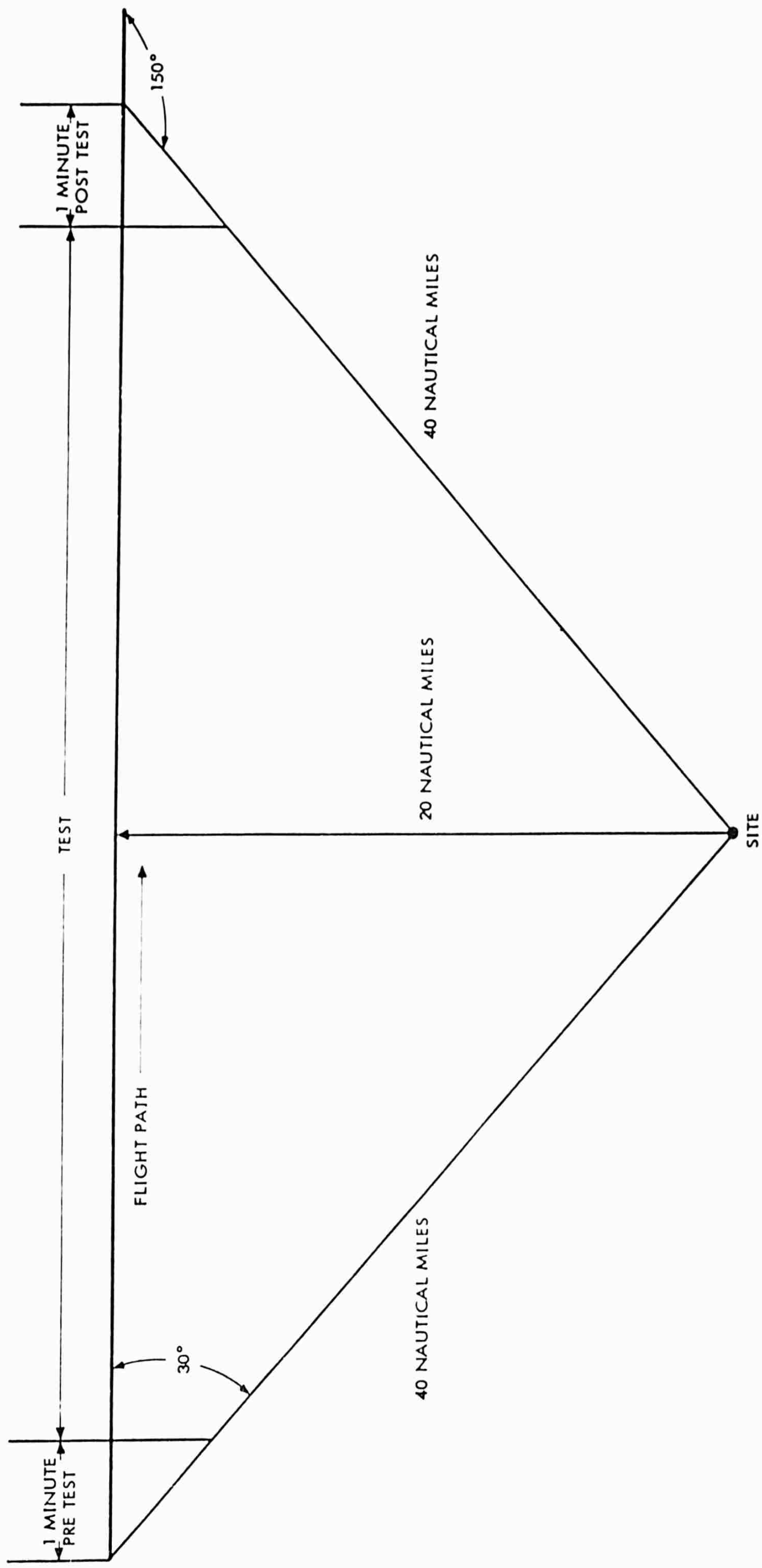


Figure 3.1-2. Flight Path Geometry for Parallel Flight Plan

3.1.2.1 Constant Angle-of-Attack Procedures. - It is assumed that the aircraft will be flown by autopilot during the crossings of the IP, as this will hold the heading closely constant. However, it cannot be assumed that the autopilot will hold pitch angle constant over widely changing flight conditions. involving progressive reduction in gross weight with fuel burn-off during the course of the test procedure.

When the autopilot is operated in the "altitude hold" mode, the resultant angle of attack, and therefore pitch, will vary with power setting of the engines and the gross weight in a predictable way: Since speed will vary as the cube root of power, and angle of attack will vary inversely as the square of speed, the power required for a constant angle of attack in level flight will vary as the 3/2 power of the weight:

$$\frac{H.P._1}{H.P._2} = \left(\frac{W_1}{W_2}\right)^{3/2} \qquad (3.1\text{-}1)$$

This relation holds true for any airplane. However, only propeller-driven aircraft are normally equipped with instrumentation enabling the pilot to set a desired horsepower level as required. This instrumentation requires at least an rpm meter (tachometer) for engine speed, and either a manifold pressure gauge or a torquemeter to measure engine torque. Some aircraft have a wattmeter-type multiplying instrument which has both torque and rpm as inputs, and reads horsepower directly.

In the case of jet-propelled aircraft, however, the power delivered by the engine is a direct function of true airspeed for any value of thrust, and the pilot cannot set a desired horsepower level by any direct method. In this case a much simpler relation can be used, as follows: For any airframe, each value of angle of attack is characterized by a constant L/D (lift-to-drag ratio) which in unaccelerated flight is exactly equal to W/T (weight-to-thrust ratio). Therefore, the jet pilot can maintain a constant angle of attack by programming the thrust in direct proportion to the weight, i.e., reducing thrust with fuel burnoff and accepting a progressive reduction in airspeed. Unfortunately, the jet engine is extremely non-linear in its production of thrust as a function of rpm, the last 20% of the rpm range accounting for (typically) up to 50% of the thrust range. Nevertheless, it is possible to establish a desired thrust level for a given set of conditions such as fuel heat content, air density, and temperature, enabling the pilot to set thrust by setting rpm. On those jet aircraft having engine pressure ratio instruments, the thrust is more directly determined.

Since the rate of fuel burnoff is predictable, or at least the pilot is aware of his fuel quantity remaining, it is possible to supply the pilot with a precomputed program of power settings for piston aircraft, or rpm or engine pressure ratio for jet aircraft, as a function of remaining fuel. Such precautions will enable the angle of attack to be held closely constant throughout the flight test, justifying the assumption of constant pitch attitude to an accuracy within the expected antenna pattern measurement accuracy of ±1°.

An alternative method of holding constant angle of attack in either piston or jet aircraft is based on the relation that for a constant angle of attack, the indicated airspeed, V_i, or dynamic pressure, Q, will vary as the square root of weight:

$$\frac{Q_1}{Q_2} = \frac{V_{i_1}}{V_{i_2}} = \left(\frac{W_1}{W_2}\right)^{1/2} \qquad (3.1\text{-}2)$$

Thus the indicated airspeed to be flown can be determined in advance for expected values of fuel load remaining. This method, however, is tedious to apply in flight since it involves long time constants and is therefore rather indirect, as well as wasteful of flight time.

Note that the L/D and W/T ratios are independent of density (a function of altitude, humidity, and temperature) since any value of L/D corresponds to some discrete value of dynamic pressure at a given weight. Thus, at higher altitudes the lower density is exactly compensated by a higher value of V^2, while the <u>indicated</u> airspeed ($\approx$ Q) remains the same for a given weight and angle of attack.

3.1.2.2 Ground-Computed Angle-of-Attack Correction. - It is possible to avoid special flight procedures such as are described above, by merely requiring the pilot to report airspeed and fuel load at the moment of passage of the IP. The reported data may then be utilized by the computer to derive attitude or angle of attack through the reverse of the computation described above for deriving a program of power or thrust settings. However, this method involves the difficulty that the angle of attack is subject to change in a more or less unpredictable way and that the depression-angle samples therefore cannot be taken at discrete increments predictable through assignment of altitude alone. Thus, it is highly desirable that angle-of-attack standardizing procedures be employed (even if ground computation of angle of attack is adopted), to permit selection of depression-angle values through selection of altitude and range.

3.1.2.3 Effect of Accelerated Flight. - Note that the effect of normal accelerations associated with maneuvering is equivalent to the effect of changes in weight in determining angle of attack. The data computation required for standardizing or deriving angle of attack is therefore simplified if all runs are made in straight and level flight at uniform airspeed, thus avoiding the angle-of-attack increments implicit in maneuvering. If the adopted technique requires the pilot to standardize angle of attack through power-control procedures as described above, then it is mandatory to employ level-flight test runs, since the pilot will have no practical means of compensating for the effects of maneuvering accelerations

3.1.2.4 Direct Attitude Measurement. - The actual pitch attitude of the aircraft can be read directly from the pitch gimbal of a vertical gyro carried in the aircraft, and can be reported to the ground for entry into the computer. However, this method will generally require either a special gyro installation or a modification to the autopilot to permit readout of the autopilot gyro gimbal angles; both may be impractical requirements. Even with direct-reading pitch instrumentation, it would still be desirable to employ angle-of-attack standardizing flight procedures to permit control of depression-angle increments through altitude assignment, as described above.

Ideally, direct-reading angle-of-attack instruments can be used by the pilot as a primary reference in those aircraft in which such instrumentation exists. In aircraft not equipped with angle-of-attack probes, one of the above-described procedural methods should be used.

3.1.3 Examples of Flight Patterns and Data Production. - Figure 3.1-3 is the result of the density pattern plot for an altitude of 20,000 ft and flight path separations of one mile. In this example, depression angles of 5 to 15 degrees were considered. An examination of Fig. 3.1-3 indicates that certain runs can be completely eliminated and others shortened without sacrificing effective coverage. Figure 3.1-4 is a plot of the remaining flights required for a three-dimensional pattern plot with 3-degree aspect angle increments and 1-degree depression angle increments for a 360-degree aspect coverage and 5 to 15 degree depression coverage. Larger increments in either aspect or depression angles would reduce the number of required flights and the corresponding flight time, while smaller increments are not justified by the accuracy of aircraft altitude measurements.

Figures 3.1-5 and 3.1-6 are the flight patterns associated with the density plots discussed previously. The figures represent the overlays which would be used with the tracking control radar plotting board. The computer would be obtaining data only during the portions of the flight represented by solid lines, thus eliminating redundant data wherever possible. In order to obtain data for a complete 3-D antenna pattern, the 26 flight paths indicated represent one-half the required data points. The pattern has to be flown in the reverse direction as well. Additional flight patterns can be devised and radar overlays prepared which would have the capability of developing antenna patterns for any requirement.

There are several exotic flight patterns that would enable excellent utilization of flight time. Various flight paths such as a spiral or a hyperbolic vertical path profile in which a constant depression angle is maintained, might be considered as possibilities. However, when the flight difficulties and calibration difficulties are considered, the problems outweigh any advantages, as explained above in Sec. 3.1.2.3.

There are several factors that influence which flight paths are advantageous. The antenna pattern requirements, such as the aspect angle resolution and depression angles of interest, the computer capability and the available aircraft time all have to be considered in selecting the preferred flight pattern. A screening angle profile map is also required to determine whether continuous tracking can take place for the various patterns under consideration.

Additional factors also have an influence upon the selection of the flight path. It is certainly desirable to utilize the autopilot whenever possible. This not only adds stability to the flights, but also aids in reducing pilot fatigue. Flying the "Parallel Time" pattern favors a maximum use of autopilot control for a given data return. The "Clover Leaf" pattern requires extensive maneuvering and vectoring to a new course for each set of data points, whereas a larger amount of data can be gathered for each linear course in the "Parallel Time" method. Both these flight plans allow the ground control tracking radar to give simple and accurate corrections to the aircraft since control overlays can be easily monitored.

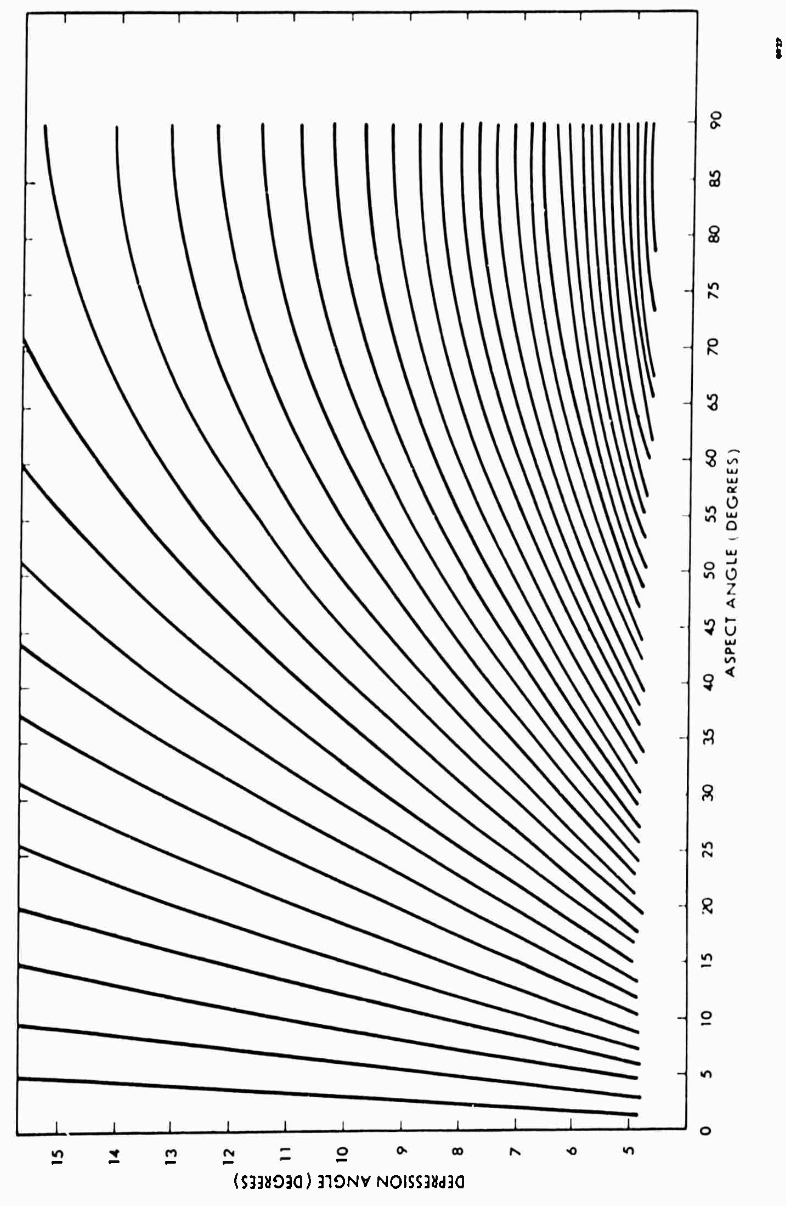


Figure 3.1-3. Depression Aspect Angles for Parallel Flight Plan

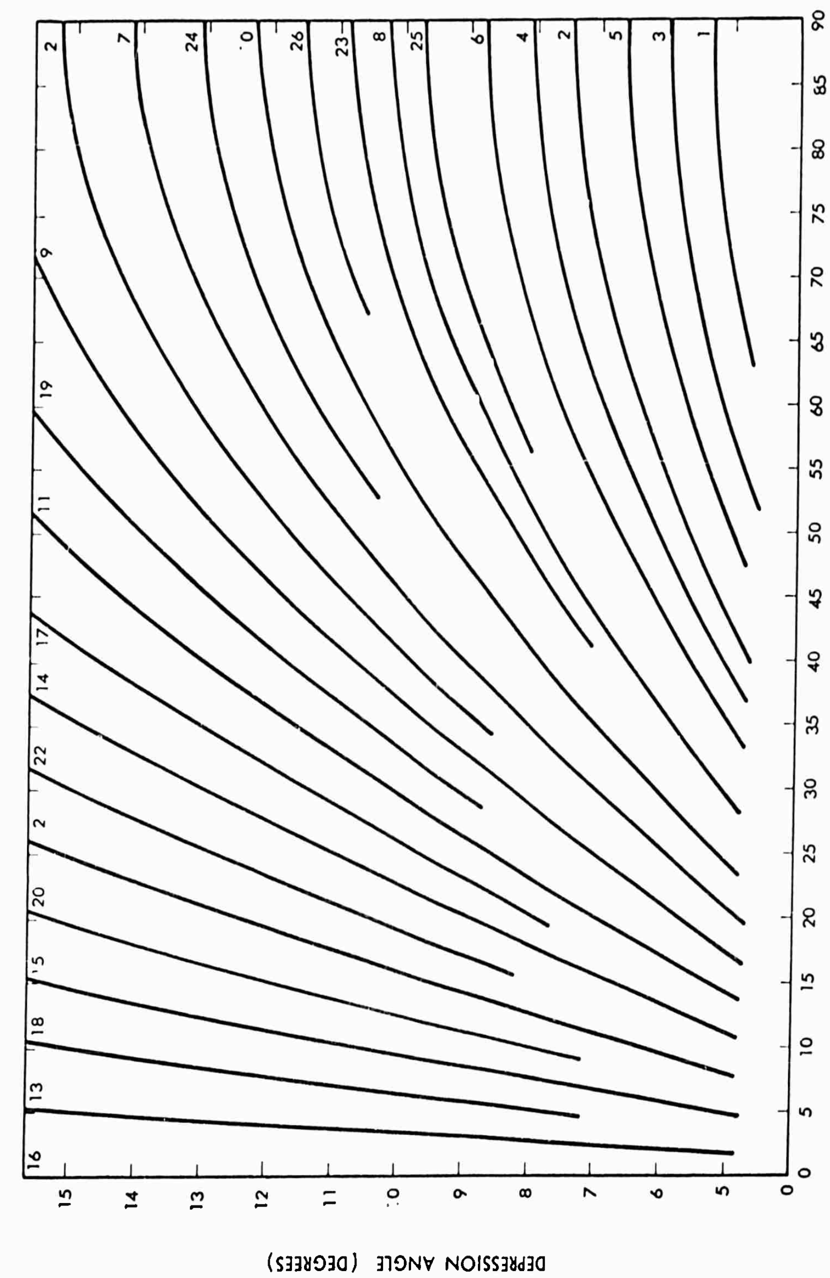


Figure 3.1-4. Simplified Flight Density Plot (Parallel Flight Plan)

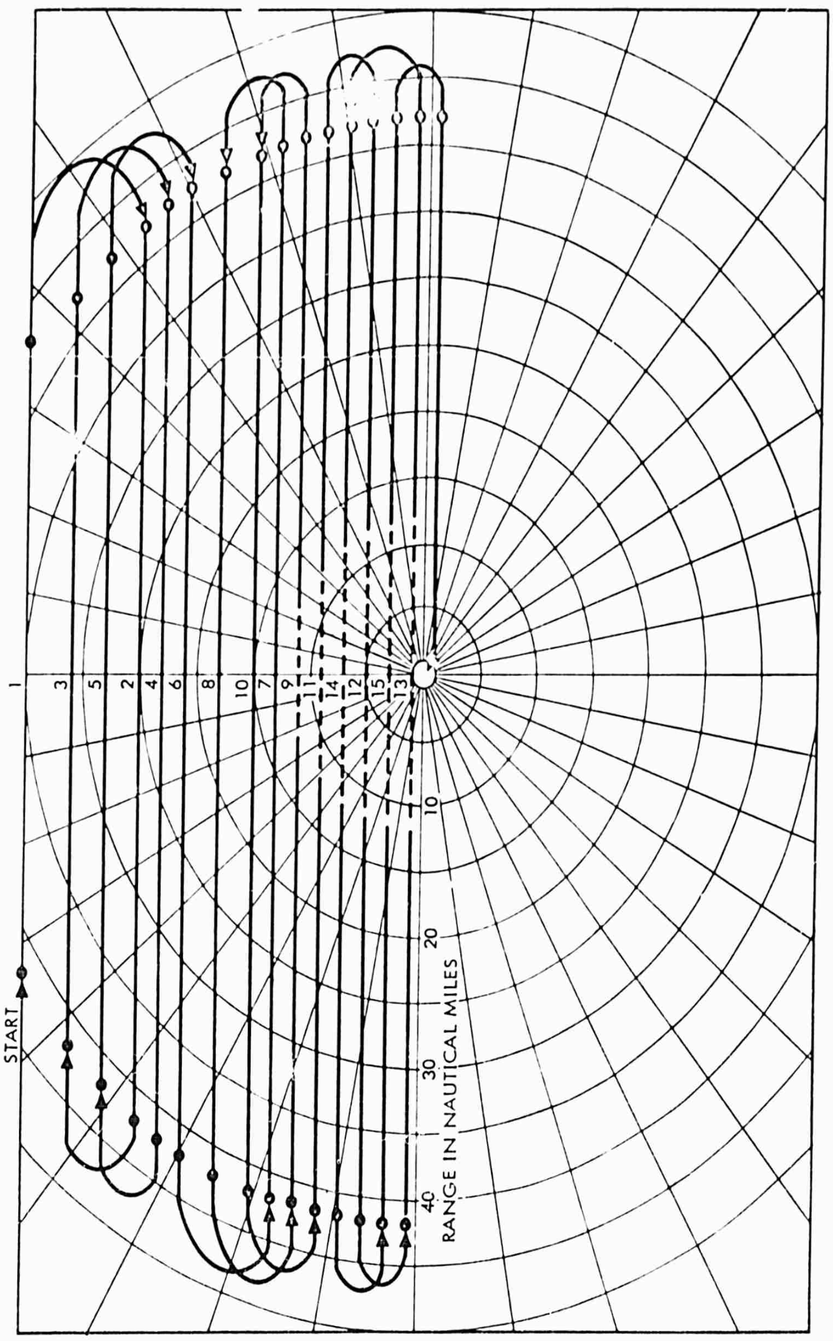


Figure 3.1-5. Typical Flight Plan for Parallel Pattern

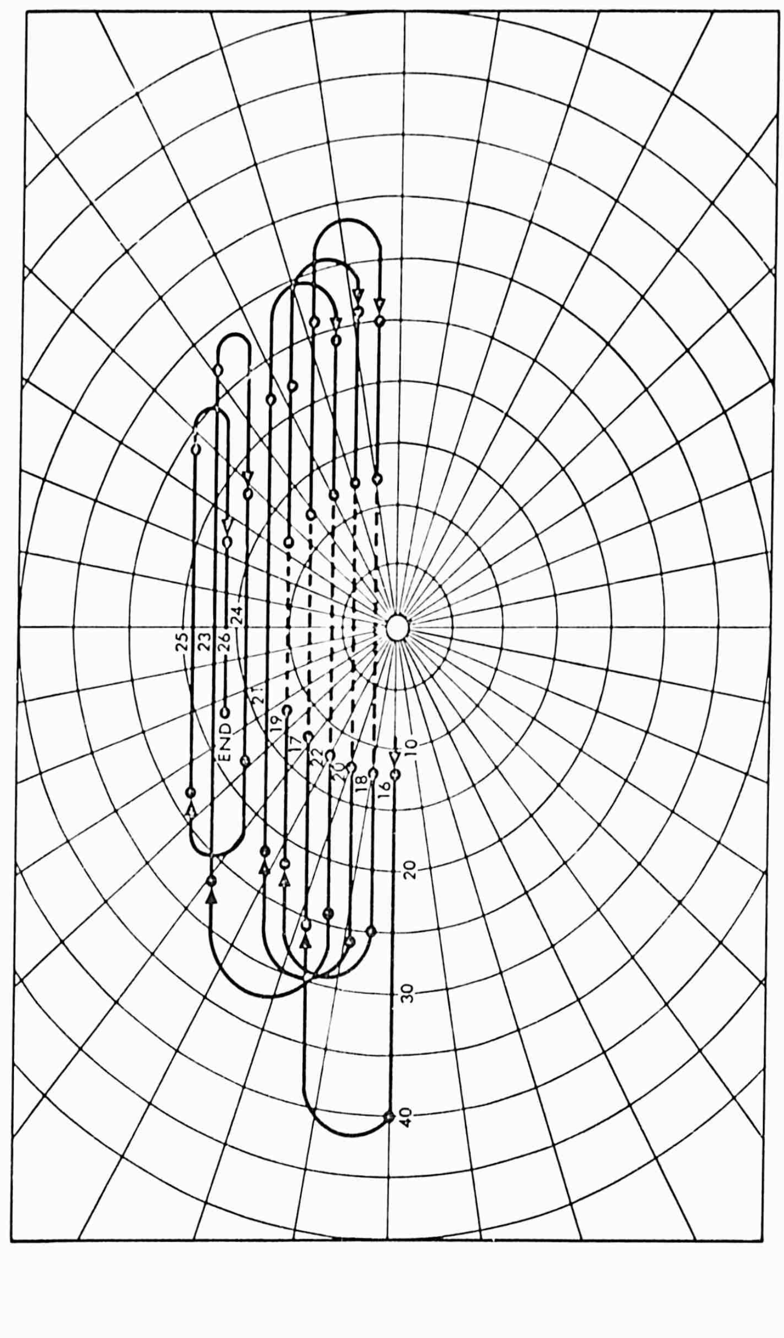


Figure 3.1-6. Typical Flight Plan for Parallel Pattern

One other aspect must also be considered when selecting the flight path, namely data accuracy. The general factors associated with data accuracy are common to all flight plans; however, the effects of different ground terrain upon the signal strength can be problematic. Since the Clover Leaf Pattern results in a complete depression-angle plot over one IP at one altitude there is no cause for concern regarding terrain blocking with this method. However, the Parallel-Time pattern is flown over an area approximately 80 miles by 35 miles, giving rise to terrain problems at low altitudes. At altitudes of 20,000 feet and greater, the difference in terrain over the area flown does not appear to present a significant effect on the data.

3.2 SYSTEM OPERATION

Successful operation of the AN/MSQ-16 requires a coordinated effort between the tracker and tracking control operator, the aircraft and pilot, and the operations personnel for the AN/MSQ-16. When operating in the slaved mode, azimuth and elevation synchro data is supplied from an external precision tracking radar to control the positioning of the receiving antenna pedestal. The aircraft is under ground control of the tracking radar by means of a voice communications link. The aircraft position is recorded on a plotting board located at the ground control tracking radar site. An overlay of the flight pattern prescribes where the aircraft should be, permitting vector control from the ground so that the pilot can be directed along the predetermined path. Utilization of a flight pattern overlay and a plotting board enable flying the optimum pattern for the required antenna pattern data and also furnish an immediate indication of whether or not the aircraft intercepted the IP within the established limits.

In the slaved-track mode it is quite evident that the tracking control operator and pilot determine to a large extent the success and accuracy of the mission. In the passive-track mode the remote tracking radar is not in the loop; however, all the operational requirements remain the same during the controlled flight. In order to perform the vector control from the ground in the passive-track mode, a plotting board must also be located in the operations control center of the AN/MSQ-16. This therefore enables the operator to monitor the flight in the slaved mode as well.

In the passive-track mode the pilot is instructed to fly to a pre-determined point in space. The antenna pedestal, under manual control, is pointed towards this point, an optical search is made by means of the television camera, and the aircraft is acquired. An r-f track can then be made and the tracking system transferred to automatic mode. The aircraft may also be initially acquired electronically. An r-f acquisition can be made by searching for and acquiring r-f radiation from the aircraft. In this procedure the television camera can be used for a visual check to insure a positive track.

Prior to the actual flight the frequencies to be employed by the airborne equipment will be made known to the ground operators. Through knowledge of the expected location of the aircraft and the type and frequencies of radiation to be employed, the probability of acquiring the wrong target will be minimized.

3.3 SITING PROBLEMS

There are three major problem areas that must be considered in establishing a location for an electronic system of the sophistication of the AN/MSQ-16. Quite obviously, the first consideration is the availability of a suitable area in which the system can perform its intended purpose. The location must be in close proximity to associated equipments that are also required for the mission. Adequate power and ancillary facilities must either be available or provisions must be made to obtain same. The remaining two areas of consideration are closely related and concern the problem of electrical interference: the location of the equipment must be such that it does not interfere with existing equipments, thereby reducing their effectiveness, while the existing equipments must not interfere with the mission of the proposed system.

The proposed location for the AN/MSQ-16 at the Verona Test Facility (see Fig. 3.3-1) apparently has sufficient room to allow for adequate equipment area and pole beacon spacing without interference with existing equipments. It also appears that there is adequate power available. Extensive work has been done at the location to verify its usability for the intended function.

An electronic and optical screening profile has been developed, as shown in Fig. 3.3-2. Observation of this figure reveals that flights incorporating elevation angles of 5 degrees or less are limited to certain azimuth corridors. Hopefully, the preferred flight areas will agree with the authorized flight areas. Several realistic cloverleaf patterns that might be flown and their approximate elevation angles are listed below:

IP Range	Altitude	Elevation
25 nm	20,000 ft	7.7°
25 nm	40,000 ft	15.5°
50 nm	20,000 ft	3.8°
50 nm	40,000 ft	7.7°

It can be seen that the 3.8° elevation flight plan is electronically screened over approximately 50% of the azimuth. Note that an aircraft flying at 300 knots travels five miles during the Pre-test and Post-test portion of the flight. Taking into consideration the turn radius required to acquire the next heading another five radial miles is required. Therefore, a tangential flight at a range of 50 nautical miles relative to the receiver site requires an additional ±12° from the selected IP to insure a solid track throughout the mission. This narrows down the usable air space to two corridors, approximately 0-45° azimuth and 115° to 170° azimuth.

An electronic screening profile is valid only for the conditions under which it was obtained. A different antenna and/or frequency will result in a different profile. Figure 3.3-2 will not be valid for the passive track mode, which will utilize the AN/MSQ-16 antennas; however, the obstacles which generate the effective profile will also be in evidence for the AN/MSQ-16 and the phenomenon must be taken into consideration.

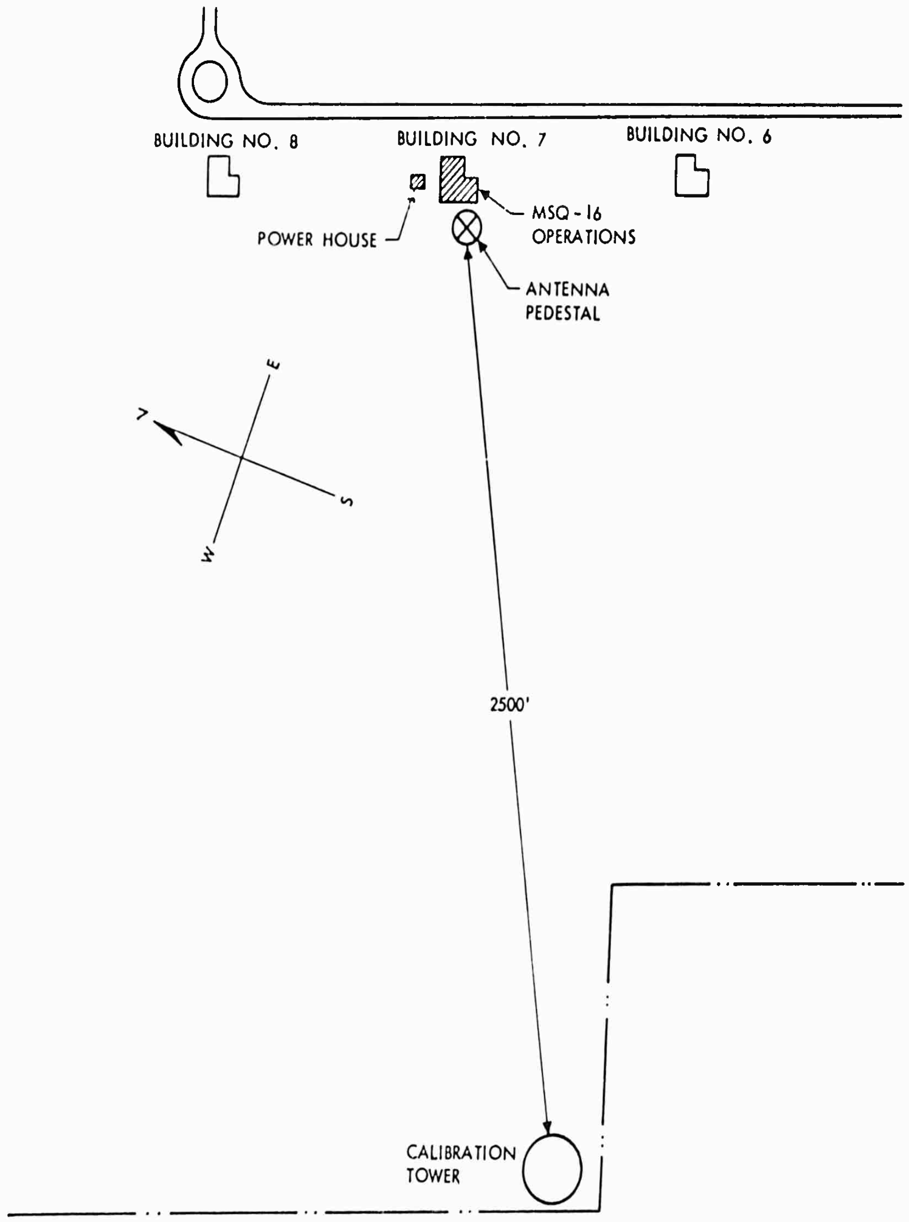


Figure 3.3-1. AN/MSQ-16 Location at Verona Test Site

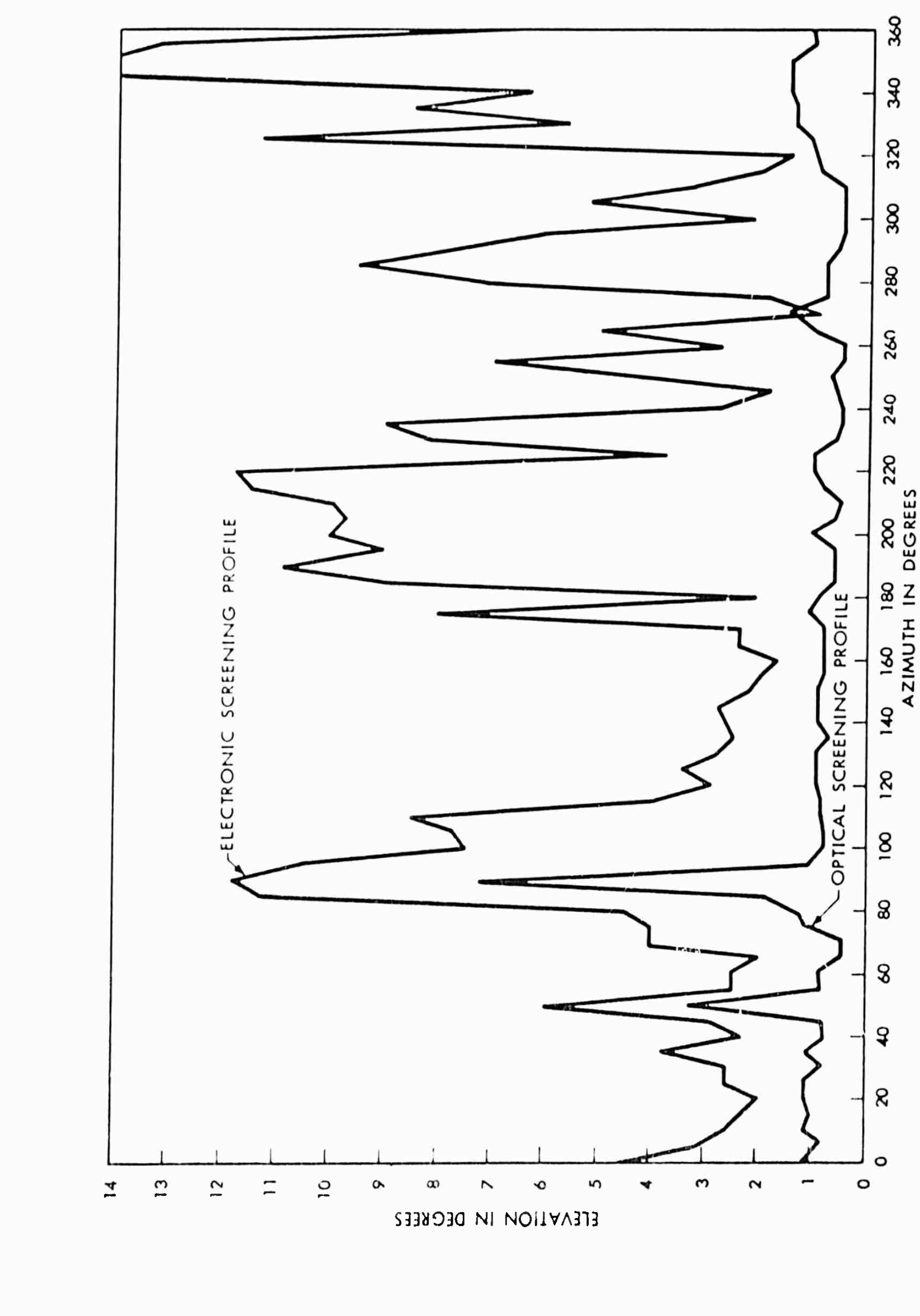


Figure 3.3-2. Electronic and Optical Screening Profile

The AN/MSQ-16, since it is a passive device, should not present any interference to adjacent electronic equipments. The only possible problem area is the physical size of the antenna pedestal.

The existence of various active systems located at the site present a large but unknown threat. To fully explore this facet, an extensive survey would have to be conducted, exploring relative signal strengths, harmonic content, antenna directivities, side lobe levels, etc. Due to the extremely wide frequency coverage of the AN/MSQ-16 most existing active systems could cause interference. Several possibilities, such as blanking areas for existing antennas, and time sharing, will have to be studied to determine the optimum solution if such a problem is found to exist.

3.4 COLLIMATION

The AN/MSQ-16, since it possesses the capability of being slaved in position to a precision tracking radar as well as the capability of passive tracking of a target, must of necessity be capable of optical and electrical collimation not only to itself, but to the tracking radar. It is assumed throughout this section that the tracking radar has been optically and electrically collimated, using present techniques. The collimation technique proposed for the AN/MSQ-16 employs closed-circuit television rather than the boresite telescope normally used. The basic procedures, however, will remain essentially the same if conventional methods are employed; therefore, only the proposed procedure will be discussed in detail.

The extremely broad frequency coverage of the system and the correspondingly complex antenna configuration require an elaborate collimation fixture or pole-beacon complex. The pole-beacon complex must contain adequate signal sources to permit alignment of all six antennas to the same optical boresite line. It is assumed that the relationship between the antennas will not have to be adjusted daily; however, the means must be provided for checking and adjusting as often as necessary.

The beacon locations on the pole can be determined from the AN/MSQ-16 antenna characteristics. The minimum spacing between the transmitting antenna and the AN/MSQ-16 receiving antennas is approximately 1200 feet. Located on the pole-beacon platform will be six low-gain antennas having the same spacing between electrical centers as their respective antennas located on the antenna pedestal, but symmetrically reversed in position as in a mirror image. Also located on the platform will be an optical target, whose center will be a surveyed point, corresponding in location to that of the television camera mounted on the AN/MSQ-16 antenna pedestal. The camera location is therefore such that when it is aligned with the optical target, all the antennas are also pointing directly toward their corresponding pole-beacon transmitting antennas. The optical center of the camera is also a surveyed point; the exact azimuth and elevation of the pole-beacon is thus established.

The antennas are next aligned, each to its respective pole beacon. Upon completion of this alignment, the antennas and camera are mutually locked. To check collimation at any later time, the pedestal is aimed toward the mount, and the pole beacon generators are energized sequentially from the control room, with the system in the passive track mode. The TV camera monitor then displays the accuracy of the respective antenna alignments by displaying the relative angular position of the camera boresite and the target located at the pole beacon mount. Any boresite error will be shown as a jump of the position of the optical target when one beacon is turned off and another is turned on.

The television camera consists of a low-light-level image orthicon tube with the required circuitry for its operation. All the controls are remoted to the operator in the control room. Included in the controls is a means of rotating a 7-position filter wheel for light control of the camera. There is a 20-db attenuation step between successive filters, permitting operation over an extremely large range of light intensity. The use of closed-circuit television has several distinct operational advantages. Quite obviously it simplifies collimation since an operator does not have to be physically present on the pedestal. This enables performing spot collimation checks in a very short period of time with one operator. The system also enables checking and adjusting the antenna servo system very simply and accurately. Although the closed circuit television system is intended primarily for collimation, it can also be used to provide viewing of the aircraft under test, and thus insure a constant check on the tracking accuracy.

Aligning the AN/MSQ-16 to the master precision tracker requires an optical procedure, again using the television circuit. Upon verification of the tracker collimation, the antenna is manually positioned to the same azimuth and elevation angles that establish the AN/MSQ-16 pole beacon relative to its antenna pedestal. The servo data from the tracker is relayed to the AN/MSQ-16 with the resulting antenna position indicating the collimation error. Any variations are then adjusted to zero. As mentioned above, a constant check on alignment of the two antenna systems can be made by means of the television camera and the monitor screen.

SECTION 4

BASIC SYSTEM CONFIGURATION

This section contains a detailed description of the AN/MSQ-16 (XW-2) configuration which has evolved as a result of the study program. Physically, the system is divided into two major groups of equipment; (1) the antenna and pedestal assembly, and (2) the main equipment group. Due to the size of the antenna assembly and the weight of the pedestal, a concrete foundation pad is employed. This provides maximum flexibility in antenna siting and main equipment group location. The main equipment group, comprising the receiving equipment, control and display console, and data processing equipment, is intended to be located in a controlled environment, within a reasonable distance from the antenna pedestal. Since all r-f equipment is located within an equipment cage on the pedestal elevation axis, signal remoting occurs at the receiver i-f frequency, allowing the main equipment group to be located up to a few hundred feet from the pedestal.

4.1 GENERAL SYSTEM DESCRIPTION

Figure 4.1-1 is a pictorial of the complete Operations Central envisoned as installed at the Verona Test Site. In addition to the antenna and pedestal group and the main equipment group (located within the building), the complete system includes an active tracking radar, facilities for communications with the test vehicle and a collimation tower. The active tracking radar and the communication facilities are not considered part of the AN/MSQ-16 (XW-2); however, provisions for mating these existing facilities with the AN/MSQ-16 should be a part of the AN/MSQ-16 equipment.

Figure 4.1-2 is a simplified block diagram of the AN/MSQ-16. This block diagram represents system with the "on-line" data-processing subsystem, employing a general-purpose digital computer. The antenna system is divided into r-f bands, as indicated, each band employing a separate antenna. Each antenna is designed with a multiple feed to provide for r-f differencing passive tracking in both azimuth and elevation.

The overall receiving system is divided into two parts, with the r-f pre-amplifier and tuning units located at the pedestal and the main receiver i-f channels located within the main equipment group. The receivers provide the capability for wide-band scanning of each r-f band or a selected portion. This mode of operation would normally be employed for location of signals and for correlating particular signals with their associated spurious signals. The receivers are capable of being tuned to any desired frequency in order to make signal amplitude measurements and accurate frequency measurements. Adequate receiver channel capacity is provided to enable

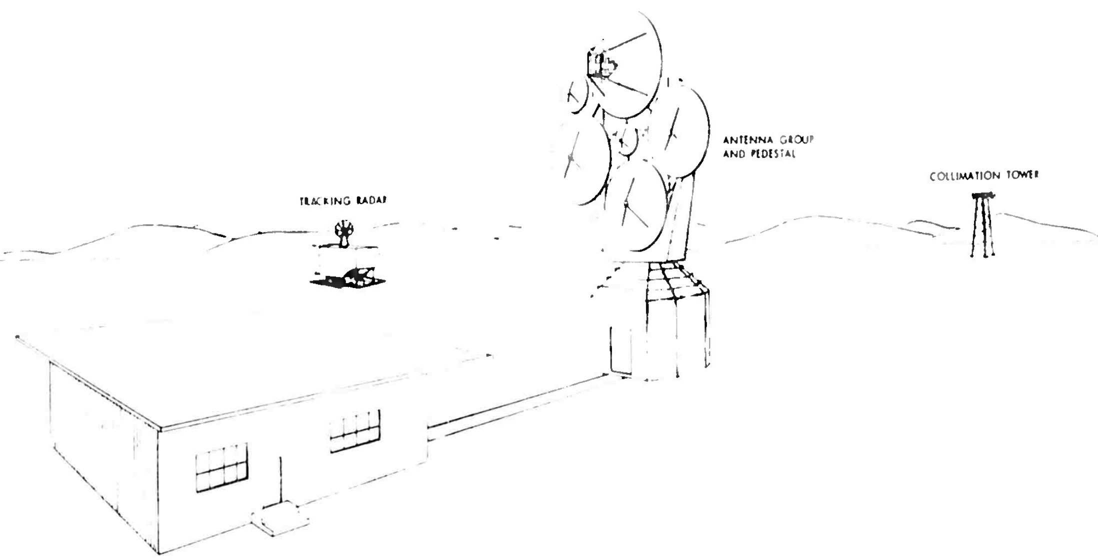


Figure 4.1-1. Pictorial of the
AN/MSQ-16 System

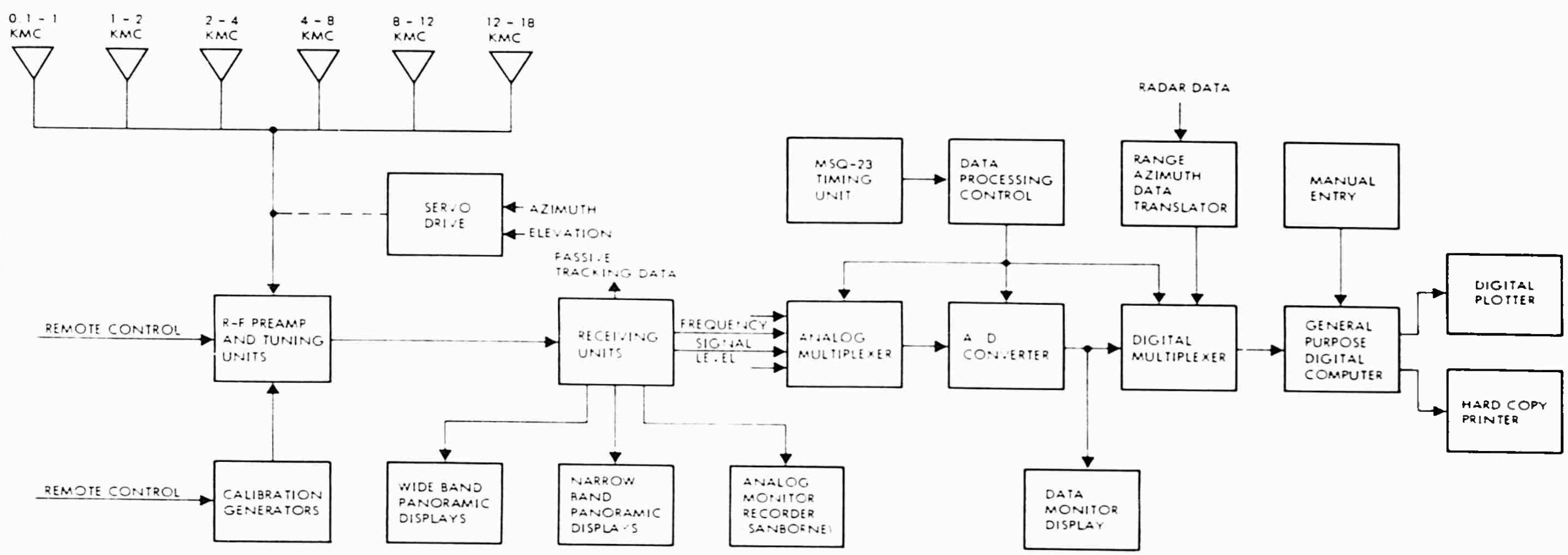


Figure 4.1-2. AN/MSQ-16 Overall Block Diagram

simultaneous operation on all bands, for both horizontal and vertical polarization, with the option of any one band being selected to govern the passive tracking function.

When any receiving band is being operated at a chosen frequency, facilities are provided for a narrow-band panoramic display. This allows monitoring of the received signal spectrum to insure that it remains within the receiver pass-band.

The receiver output data, i.e., signal amplitude and frequency, are supplied to the data processor. Analog data is multiplexed and digitized and combined with the vehicle position data and manual input data for application to the computer. The principal functions of the computer are (1) to determine the direction of the radiation vector relative to a vehicle reference. In the case of an aircraft antenna pattern measurement, the computer will determine the radiation direction relative to the aircraft, i.e., bearing and depression angle from the aircraft's longitudinal axis and horizontal plane respectively. (2) The computer will then associate a horizontal and vertical polarization signal amplitude with the corresponding direction vector to enable a direct plot of the antenna pattern. (3) Hard copy print-out (paper tape) is also provided to tabulate the data and associate it with other significant data such as test identification, frequency, time, vehicle position, etc. (4) An additional analog recording facility is provided to give the operator the capability of selectable monitoring of signal amplitude. This also provides an aid for pre-test check-out of the system.

The Control Console, illustrated in Fig. 4.1-3 provides several functions. The important ones are:

a. A monitor capability, displaying numerically any selectable parameter being processed by the data processing system.

b. A keyboard for manual entry of various data with concurrent verification on the numeric display.

c. The various system controls such as mode selection (Sweep: sector width and centering/Non-sweep: manual tuning); mount control (manual, or automatic with band and polarization selection); computer control; calibration generator tuning; calibrate "on/off"; receiver parameter selection (IF bandwidth, detector type, etc.).

d. The Wide and Narrow panoramic displays.

The design of the console is such that control of the complete AN/MSQ-16 function can be accomplished by a single operator.

4.2 ANTENNA CONFIGURATIONS

Section 2.1 of this report discussed the antenna performance requirements of the AN/MSQ-16. Table 2.1-2 of that section contains a tabulation of the antenna requirements as a result of received signal level requirements. As indicated in the discussion, two versions of the Band 1 antenna were considered. The first approach employed a two-dimensional array of log-periodic

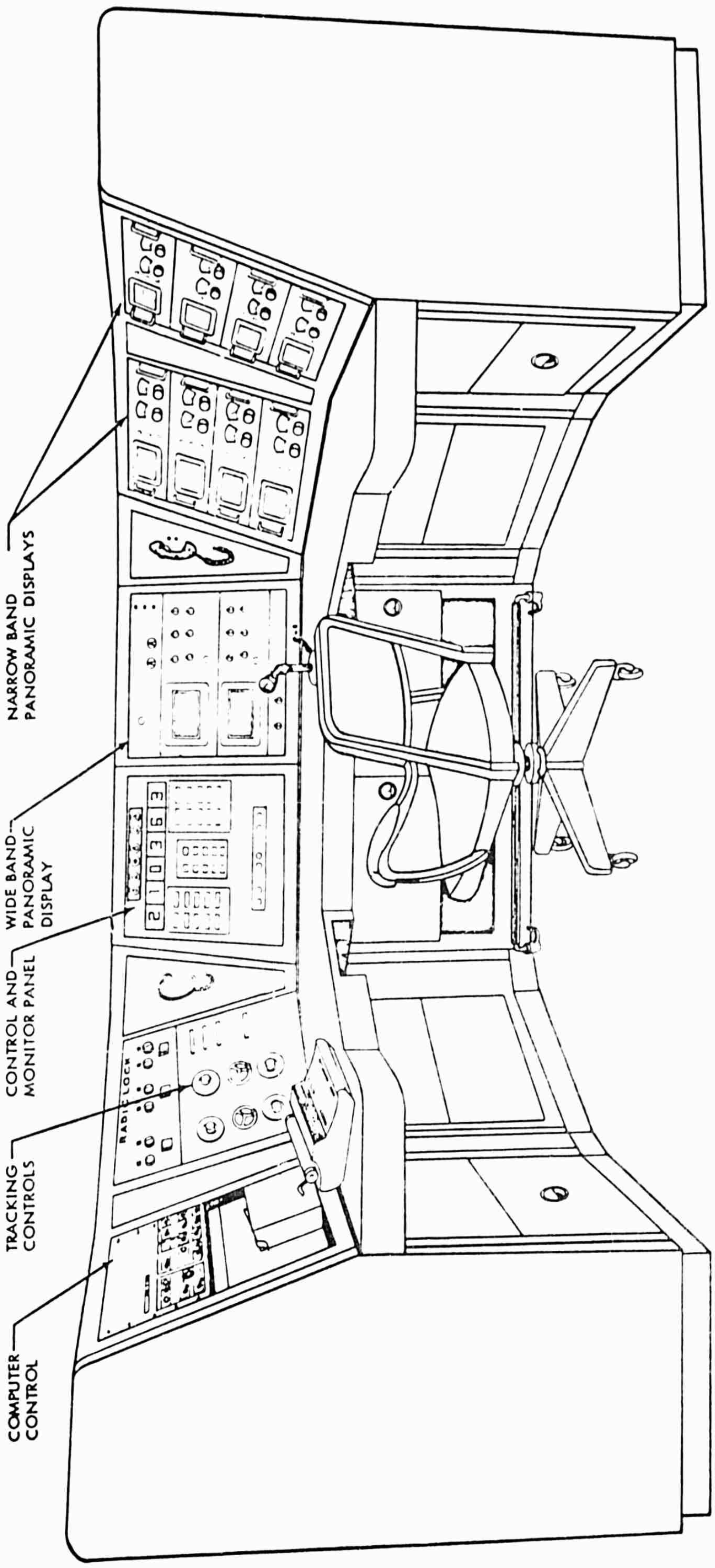


Figure 4.1-3. Control Console Pictorial

elements. The second approach employed a similar type log-periodic array employed as the feed for a parabolic reflector. The characteristics of this latter configuration were considered more advantageous from a system standpoint as its gain increases as the square of frequency, whereas the plain array has a gain which is independent of frequency. However, it would be more complex than the plain array and would result in increased wind loading on the pedestal.

It has been concluded that, in spite of the additional complexity of the log-periodic fed parabolic antenna, this antenna should be employed in the AN/MSQ-16. The principal reason for this choice, in addition to the increased antenna gain with frequency, is the correspondingly narrower beamwidths at the higher frequencies. This will provide a major increase in the passive tracking capability at the higher Band 1 frequencies, particularly from the standpoint of minimizing the effect of ground reflections.

Figure 4.2-1 is an outline drawing of the Band 1 antenna. The reflector diameter has been chosen to be 17 feet in order to insure a gain of 11.5 db at 100 mc. The ratio of focal length to diameter is 0.5. A higher f/d ratio would be desirable to reduce the effects of de-focusing due to phase center changes in the log-periodic feed with frequency. However, an increase in the f/d ratio would cause increased mechanical problems in supporting the feed. Additionally, the feed itself would have to be longer to provide a narrower primary beamwidth.

It is difficult at this time to completely design the feed without obtaining additional experimental data. The principal problem expected is the determination of the log-periodic array configuration to achieve a specified illumination pattern. For the diameter and f/d ratio chosen, the array pattern -8 db beamwidth should be 106 degrees. This will provide -10 db illumination at the reflector edges due to a relative space attenuation of 2 db between the edge path length and path length to the reflector center.

As indicated in Sec. 2.1, the vertex of the feed should be located slightly on the reflector side of the focus to minimize the defocusing effects of movement of the feed phase center with frequency.

One design problem that will exist is the problem of obtaining similar E- and H-plane primary patterns. This problem is further complicated by the dual-polarization requirements. This requires that the feed be symmetrical about its axis, so that different element spacings cannot be employed to equalize the E and H patterns. The exact effect this problem will have is difficult to determine without experimental data; however, it is expected that a compromise design can be accomplished, which will tend to optimize the low-frequency performance at the expense of performance at the higher frequencies.

The Band 2 antenna employs a design similar to that employed by Band 1. Here it is expected that the design will be somewhat easier due to the smaller fractional bandwidth. A reflector diameter of 12 feet has been chosen to provide the required gain.

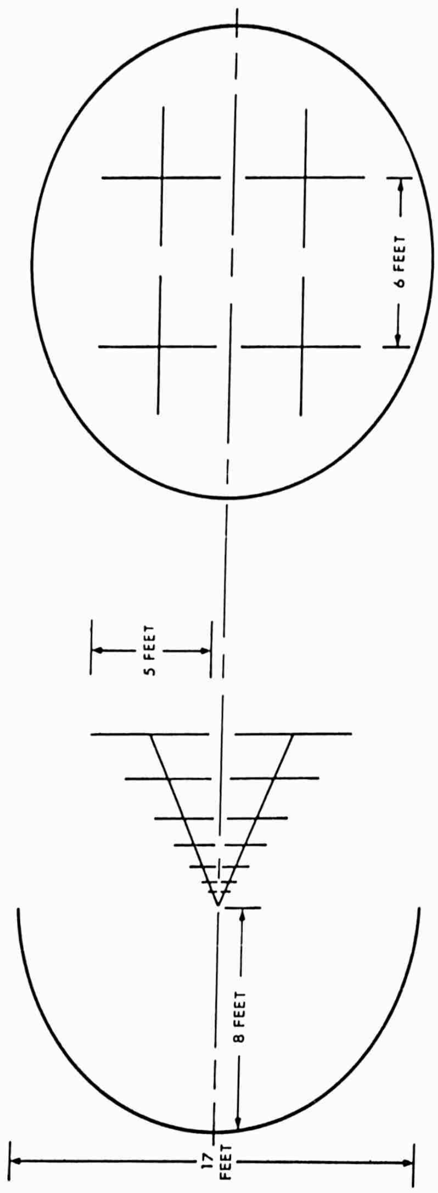


Figure 4.2-1. Layout of the Band 1 Antenna

The Band 3 antenna can be either of this basic design or of the design employed for the higher-frequency bands. The choice is somewhat dependent upon the comparative performance achieved between the low-frequency and high-frequency configurations. It is anticipated that the wide-band horn-feed configuration employed at the higher frequencies will have superior performance in terms of efficiency and side-lobe levels than the lower-frequency antennas. The use of the low-frequency configuration has the advantage of an increase in gain with frequency, making maximum use of the available aperture across the band. The antenna choice for this band can be made once performance data is available on the other antennas. A 12-foot diameter reflector will be required to achieve the desired gain for Band 3.

The remaining bands, i.e., Band 4, Band 5 and Band 6, each employ a four-horn feed to illuminate a parabolic reflector. In order to achieve operation over a 2:1 frequency range, ridged wave guide and horns will be required.

The problem of obtaining symmetrical E- and H-plane primary patterns and dual polarization will exist here as well as with the low-frequency feed. Here again the horn must be symmetrical so that the E and H planes can be reversed to provide dual polarization. This has been accomplished over somewhat narrower bandwidths with square compound horns and wide-band operation has been achieved with circular horns with ridges in each quadrant.

In all the antenna configurations discussed, the feed primary pattern is designed to be essentially optimum for the sum pattern. The difference pattern will then be dependent upon the squint angle of the individual elements. In the case of the log-periodic feed, the squint angle is a function of the angles formed at the vertex of the feed. This in turn is dependent upon the desired sum pattern primary beamwidth (or f/d ratio) and the array spacing.

In the case of the four-horn feed, the squint angle is a function of the horn dimensions which determine the distance at which the horns must be mounted off the reflector focus. In general it is difficult to achieve the optimum beam crossover for maximum difference-pattern slope, and a beam crossover will normally occur in the region of the -3 db points. However, this effect does not represent a serious loss in difference-pattern slope.

One additional consideration is the allowable cross-polarization coupling allowed. This is dependent upon the ratio of cross-polarized signal components from the radiation source. If the signal source antenna is a well designed symmetrical structure the ratio of cross-polarized energy radiated can be as high as 40 db. In order for the AN/MSQ-16 to make accurate relative polarization measurements, the cross-polarized isolation of its antenna should be somewhat greater, which would be quite difficult to achieve. However, it can be expected that the radiating source antenna will be mounted in the vicinity of a complex surface significantly increasing the cross-polarized radiation. At present, it appears that the AN/MSQ-16 antennas should have a cross-polarization isolation of at least 30 db.

4.3 PEDESTAL

The pedestal required to support the AN/MSQ-16 antennas and r-f equipment must be capable of being servo controlled in both the azimuth and elevation planes. For this application a conventional altazimuth type mount with the elevation axis above the azimuth axis is well suited. In a mount of this type, one of the major sources of loading on the mount drives is the anticipated wind loading. The wind loading for a particular wind velocity is in turn a function of the frontal area presented to the wind and the particular type of structure.

Figure 4.3-1 is a possible layout of the various antennas as viewed from the front of the antenna structure. The dotted line is shown for reference to indicate a diameter of 30 ft. This particular grouping of the antennas was chosen for two reasons. First it is desirable to group the higher frequency antennas near the lowest frequency antennas as the large feed projecting from the low frequency antenna will not block the high frequency antenna due to their narrow beamwidths. The second consideration was to group the antennas such that their frontal area is approximately equally distributed about the elevation and azimuth axis to reduce wind torques. Table 4.3-1 is a tabulation of the antenna bands together with their reflector diameters, projected frontal areas and estimated weights. The estimated weights include the individual antenna back-up structure and feeds, but do not include the pedestal structure to support the antennas. This structure, plus the electronic equipment and elevation drive is estimated to weigh an additional 2,200 lbs, bringing the total weight on the elevation axis to approximately 4,050 lbs.

The wind loading for this frontal area can be obtained from the following relation (Ref. 8)

$$F = k_f A V^2 \qquad (4.3\text{-}1)$$

where:

F = the wind loading in lbs.

kf = a coefficient dependent upon wind direction, the reflector construction, and air density.

A = frontal area.

V = wind velocity, mph.

For design purposes, a maximum operational wind velocity can be assumed to be 60 mph. A value of k_f of 0.25×10^{-2} (Fig. 2.10 of Ref. 8) is assumed for this configuration. This value is between that given for solid reflectors and slotted reflectors, as it is anticipated that the major reflector area will be of wire mesh or expanded metal construction. This gives a value of 6,300 lbs for the maximum operating wind force at normal temperatures. However, this value must be increased by approximately 25% to include the effects of increased air density at low temperatures (-40°F). This brings the maximum operating wind force to 8,200 lbs.

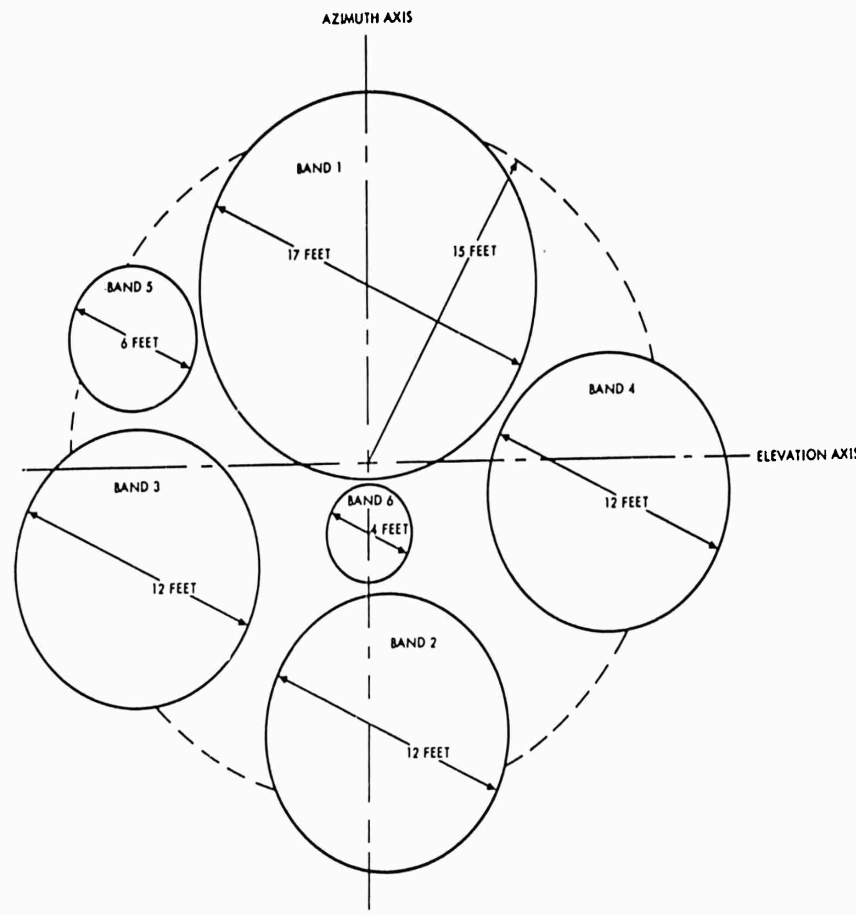


Figure 4.3-1. Layout of the Antenna Grouping

TABLE 4.3-1

SUMMARY OF ANTENNA AREAS AND WEIGHTS

Band	Reflector Diam Feet	Frontal Area Sq. Feet	Estimated Weight Lbs.
1	17	228	900
2	12	116	250
3	12	116	250
4	12	116	250
5	6	28.4	150
6	4	6.3	50

Total 610.7 sq ft 1,850 lbs

The turning torque produced by unbalanced wind loading may be found from a relation identical to that for wind loading except for a different coefficient. Figure 2.11 of Ref. 8 gives this coefficient as a function of wind direction, for slotted and solid reflectors. Here again, it can be expected that the AN/MSQ-16 antenna configuration will lie between these two types of construction. Assuming a value of coefficient of wind torque of 0.7×10^{-3} and the worst wind direction relative to normal incidence ($\approx 100°$) a wind torque of 1760 ft-lbs is obtained for a 60-mph wind.

In order to estimate the required servo drive power, an estimate of the mount moment of inertia, and the maximum expected angular tracking velocity and acceleration must be made. The maximum angular velocity and acceleration can be determined by considering the tracking rates encountered by a worst case. If it is assumed that the AN/MSQ-16 is required to track a target which can fly past the tracking site on a constant heading, with a particular velocity, minimum range and altitude, the required tracking velocities and accelerations can be easily calculated. This situation is illustrated in Fig. 4.3-2.

In the azimuth plane,

$$\omega_a = \frac{v}{r_o} \cos^2 \theta \qquad (4.3\text{-}2)$$

$$\alpha_a = \frac{v}{r_o} \sin^2 \theta \qquad (4.3\text{-}3)$$

where:

ω_a = azimuth angular velocity rad/sec.

α_a = azimuth angular acceleration rad/sec/sec.

The maximum angular velocity occurs at $\theta = 0$, and ω_a (max) = v/r_o. The maximum acceleration occurs at $\theta = \pi/4$ and α_a (max = v/r_o. However, as far as the servo power is concerned, neglecting wind torque, maximum power is required when the product of acceleration and velocity is a maximum. This occurs at $\theta = 7.25°$ and

$$\omega_a \, \alpha_a \,(\text{max}) = 0.244 \, \frac{v^2}{r_o^2}$$

The power required then becomes:

$$P = \omega_a \, \alpha_a \, I = 0.244 \, \frac{v^2}{r_o^2} \, I \qquad (4.3\text{-}4)$$

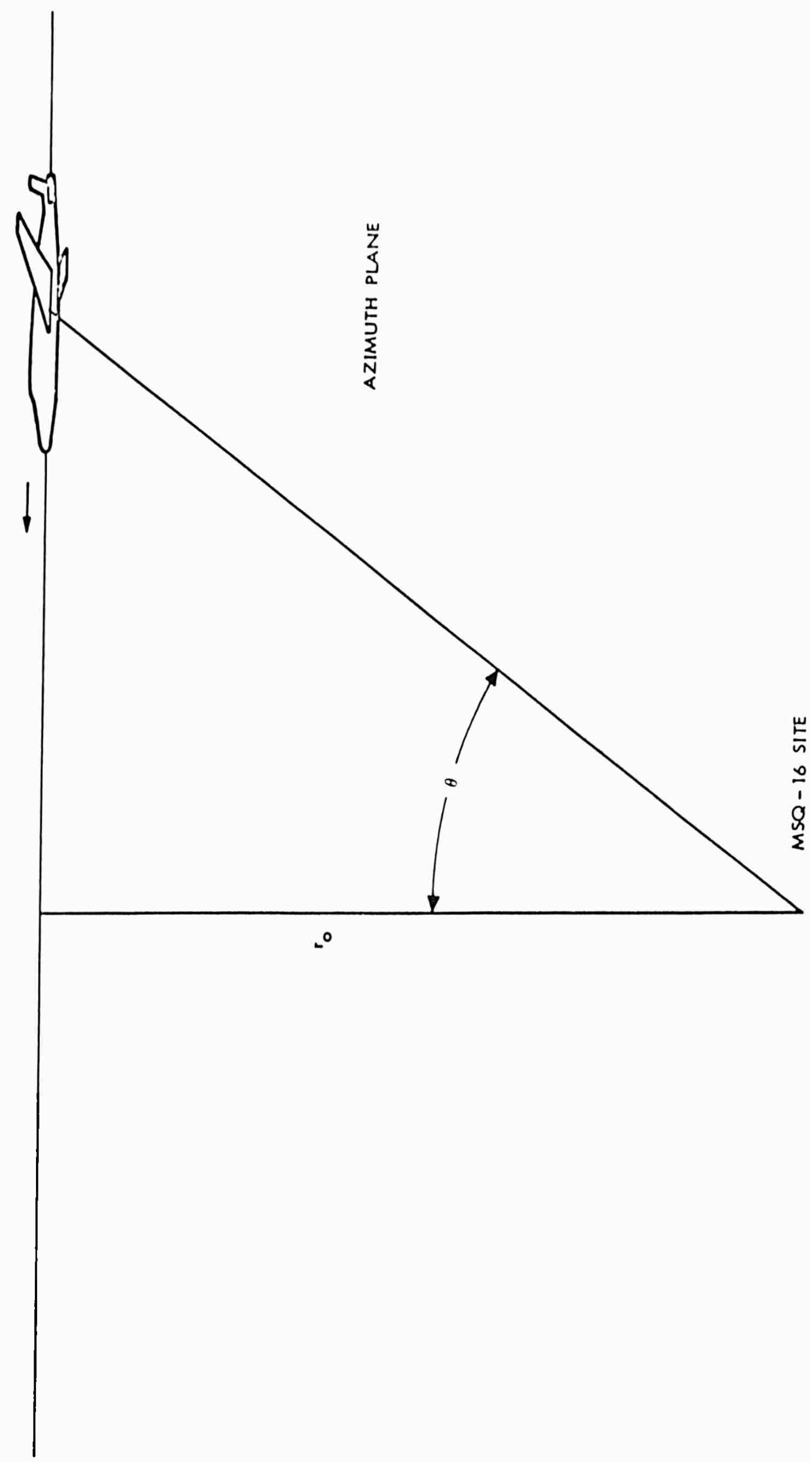


Figure 4.3-2. Model for Determination of Azimuth Angular Rates

where:

I = the moment of inertia about the azimuth axis.

An additional consideration is the power required to maintain a given angular velocity in the presence of wind torques. This power reaches a maximum at maximum tracking velocity. As a first approximation, this power can be computed at maximum velocity and added directly to that due to mount inertia. The power required to overcome wind torque T_w is given by:

$$P = T_w \omega_a \tag{4.3-5}$$

In the case of the AN/MSQ-16 azimuth drive, representative parameters for a worst case can be assumed as $v = 600$ knots and $r_o = 1$ nm. The moment of inertia about the azimuth axis is estimated to be 5,000 slug-ft^2. Foi this case, the power required due to inertia is 650 ft lbs/sec or 1.2 hp. The power required to overcome wind torque is 0.53 hp and the total is 1.73 hp. Since various gross estimates are involved in these calculations some safety factor would normally be added to this value and a drive power of at least 2.5 hp should be employed.

The situation in elevation generally requires less power than that of azimuth due to lower accelerations and lower moment of inertia. Typically the elevation drive power is on the order of 60% of the azimuth requirement.

In addition to the operating situation, one must consider the non-operating or stowed forces that can act upon the mount. With a mount of this size, it is general practice, to stow the mount with the antennas pointing directly to the zenuth. This position minimizes the effects of horizontal wind forces. The design should be such that the antennas and mount can survive, when in the stowed position, in winds of up to 120 mph. This is not a particularly severe problem if the mount can be properly stowed.

The following is a summary of the AN/MSQ-16 mounts requirements.

1.	Height	25 feet to the elevation axis
2.	Azimuth rotation	continuous
3.	Elevation rotation	-5 deg to +95 deg
4.	Position accuracy	± 1 mil
5.	Tracking rates	
	a) azimuth	10 deg/sec max, .002 deg/sec min
	b) elevation	5 deg/sec max, .002 deg/sec min

6. Acceleration

   a) azimuth & elevation — 10 deg/sec^2

7. Synchro Input (slaved or manual tracking) — 1 x, 16 x and 36 x

8. Operating wind velocity (no ice) — 60 mph

9. Non-operating wind velocity (with 1/2 inch ice). — 120 mph

10. Mount should have provisions for the following:

    a) Automatic braking upon power failure

    b) Elevation limit switches and mechanical stops

    c) Provisions for leveling

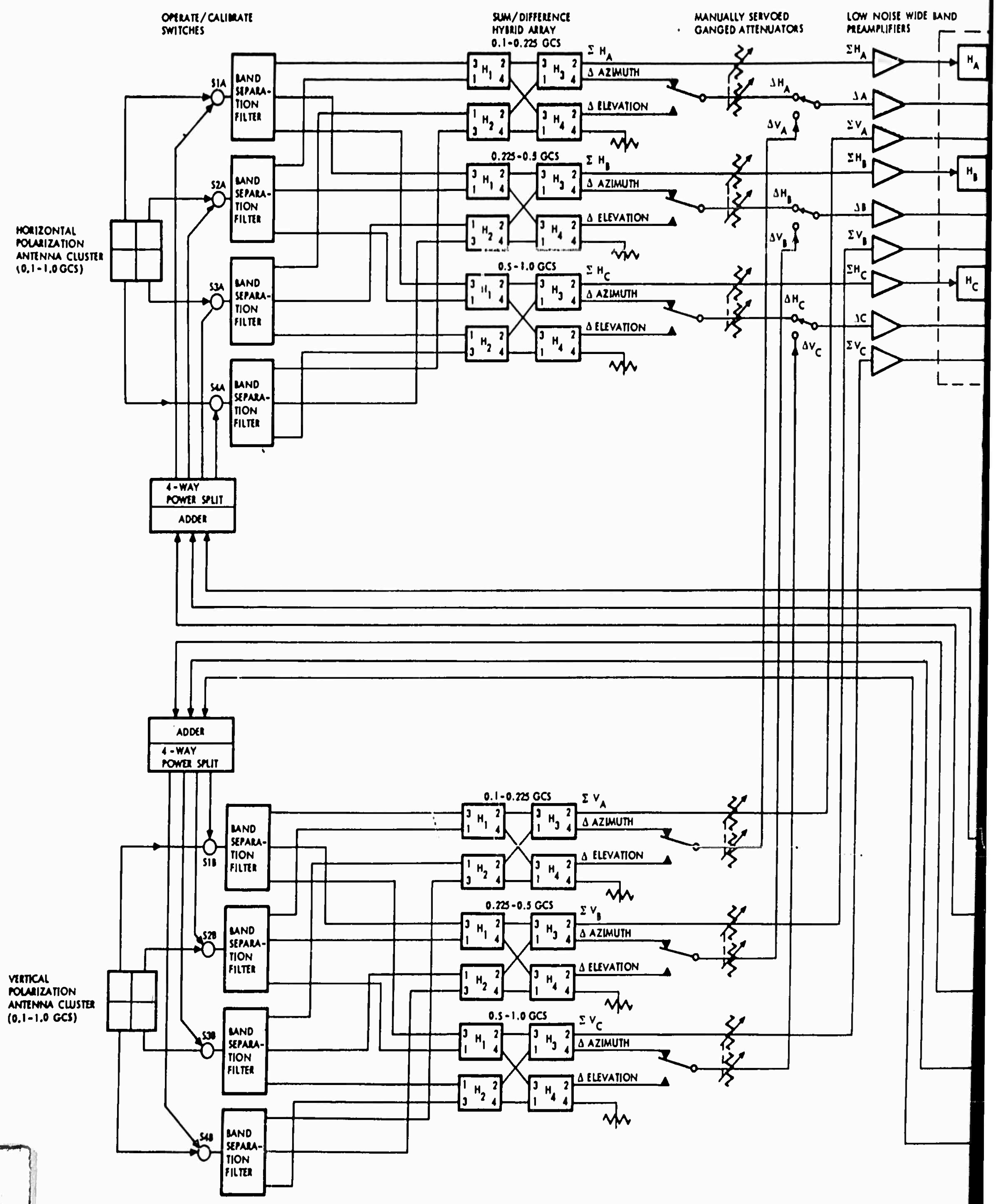
    d) Boresite alignment provisions.

4.4 RECEIVERS AND CALIBRATION

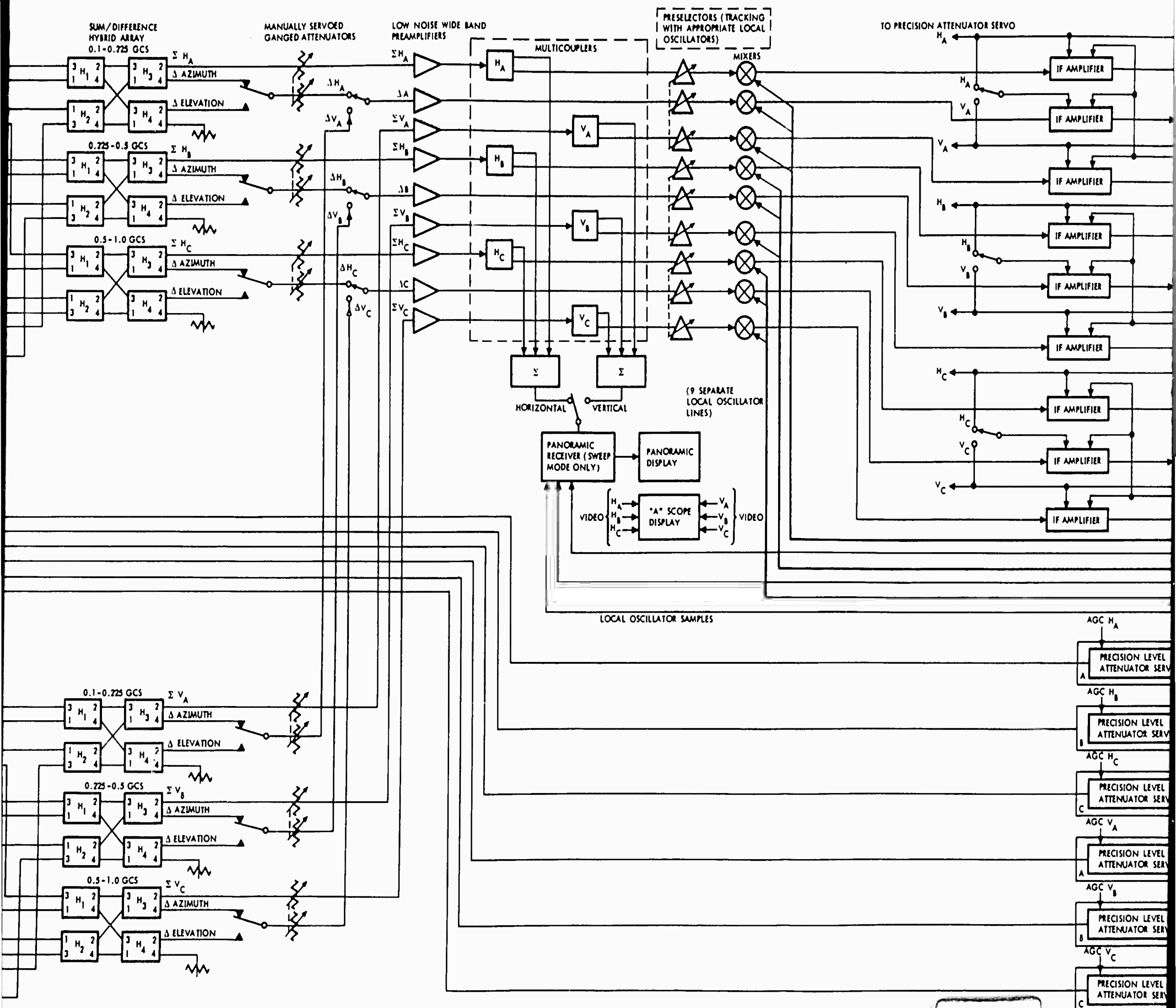
The recommended receiver complex is shown functionally in Figs. 4.4-1 through 4.4-4. It does not include the system of Ref. 34 which was considered unacceptable due to the excessive number of mixers employed, together with the impracticality of wide open reception of octave frequency bands, namely 0.1 to 0.2 and 1.0 to 2.0 Gcs, making second harmonic spurs impossible to eliminate. Overall system spur response would be excessively difficult to keep within tolerance.

Availability and flexibility were the main deciding factors in selecting the recommended complex. No item requiring development is called out where it could be avoided by revision of system concept.

Bands 2, 3, and 4, are seen to be functionally identical. Also, Bands 5 and 6 are functionally identical. Band 1, however, must be unique. The decade sweep coverage requires that Band 1 be translated to a microwave frequency where a BWO sweeper may be used. See Fig. 4.4-2. Translation back down to i-f then follows. The problem of residual FM introduced by the BWO, makes fixed-frequency operation of this receiver unsuitable for narrow-band reception. The peak residual FM varies typically from 60 Kcs in the 1-2 Gcs band to 180 Kcs in the 12-18 Gcs band, and these values are representative of the current state of the art. Inasmuch as several communications systems operate on bandwidths much narrower than the 1.5 Mcs minimum, it is very likely that this should be the maximum bandwidth for the Band 1 receiver and that the peak residual FM be kept below 10 Kcs.


OPERATE/CALIBRATE SWITCHES
SUM/DIFFERENCE HYBRID ARRAY
0.1-0.225 GCS
MANUALLY SERVOED GANGED ATTENUATORS
LOW NOISE WIDE BAND PREAMPLIFIERS
BAND SEPARATION FILTER
0.225-0.5 GCS
0.5-1.0 GCS
Δ AZIMUTH
Δ ELEVATION
HORIZONTAL POLARIZATION ANTENNA CLUSTER (0.1-1.0 GCS)
VERTICAL POLARIZATION ANTENNA CLUSTER (0.1-1.0 GCS)
4-WAY POWER SPLIT
ADDER
S1A
S2A
S3A
S4A
S1B
S2B
S3B
S4B

1


SUM/DIFFERENCE HYBRID ARRAY
0.1-0.225 GCS
0.225-0.5 GCS
0.5-1.0 GCS
Δ AZIMUTH
Δ ELEVATION
MANUALLY SERVOED GANGED ATTENUATORS
LOW NOISE WIDE BAND PREAMPLIFIERS
MULTICOUPLERS
PRESELECTORS (TRACKING WITH APPROPRIATE LOCAL OSCILLATORS)
MIXERS
TO PRECISION ATTENUATOR SERVO
IF AMPLIFIER
HORIZONTAL
VERTICAL
(9 SEPARATE LOCAL OSCILLATOR LINES)
PANORAMIC RECEIVER (SWEEP MODE ONLY)
PANORAMIC DISPLAY
VIDEO
"A" SCOPE DISPLAY
LOCAL OSCILLATOR SAMPLES
AGC H_A
AGC H_B
AGC H_C
AGC V_A
AGC V_B
AGC V_C
PRECISION LEVEL ATTENUATOR SERV

2

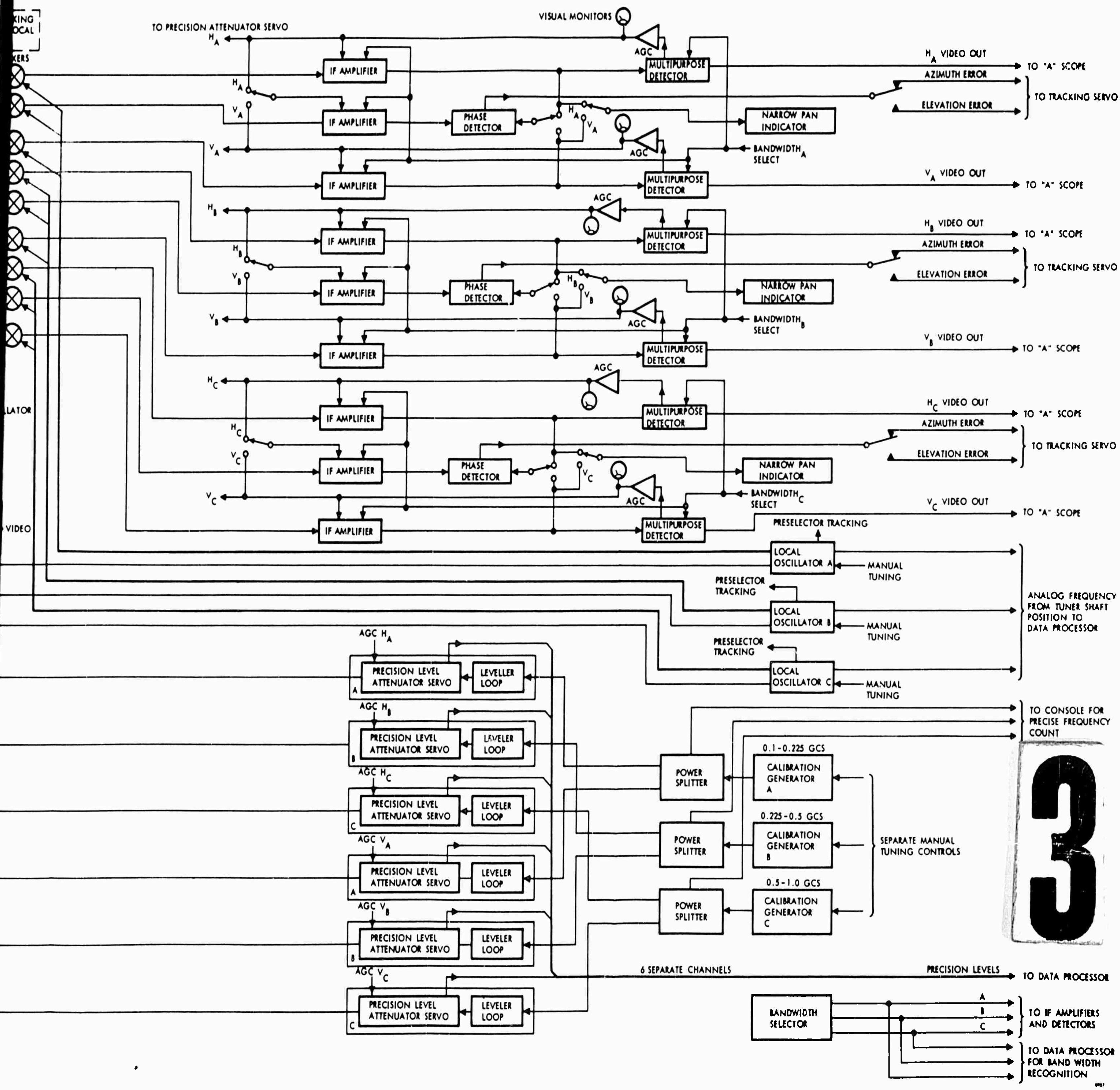


Figure 4.4-1. Block Diagram, Band 1 Receiver Configuration

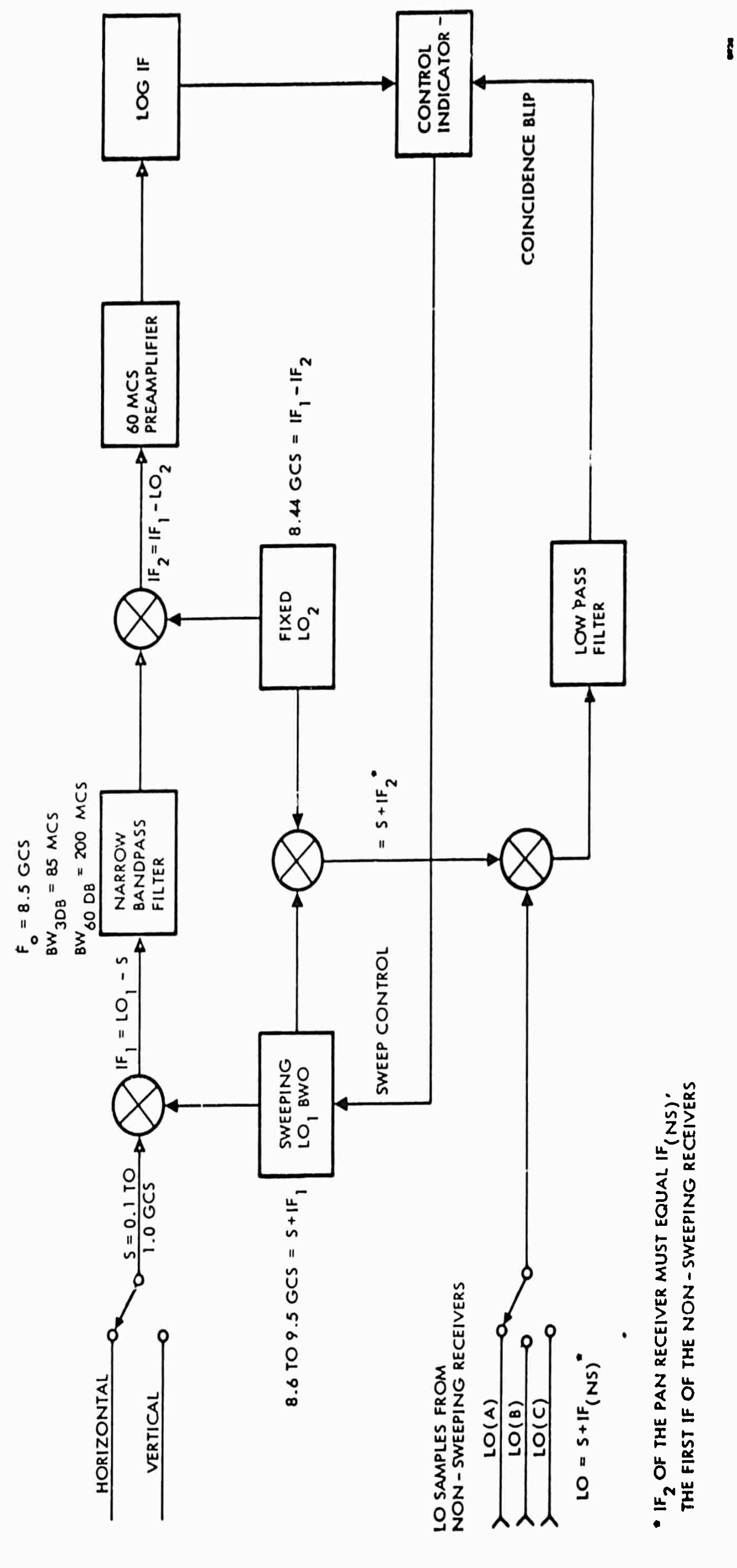
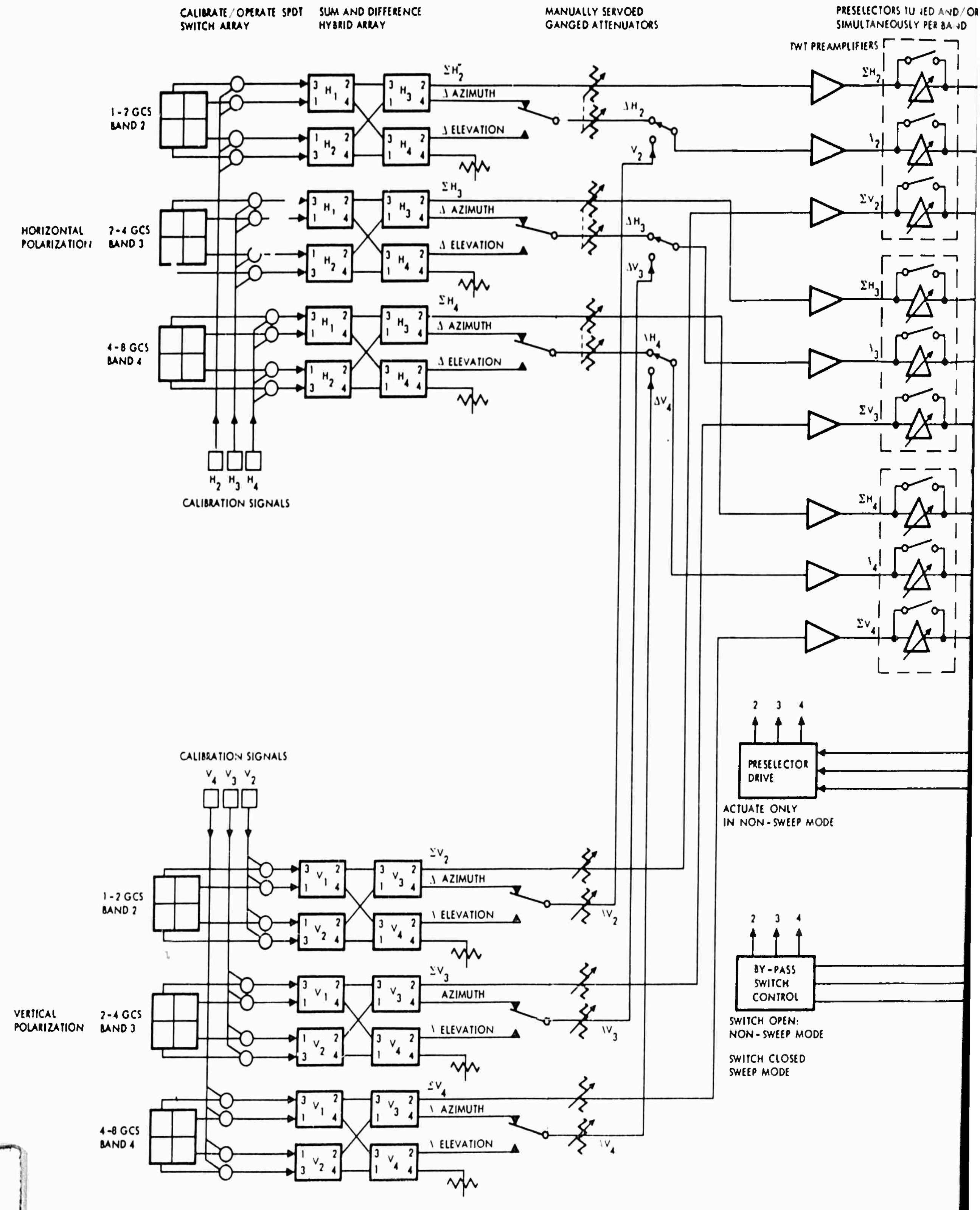
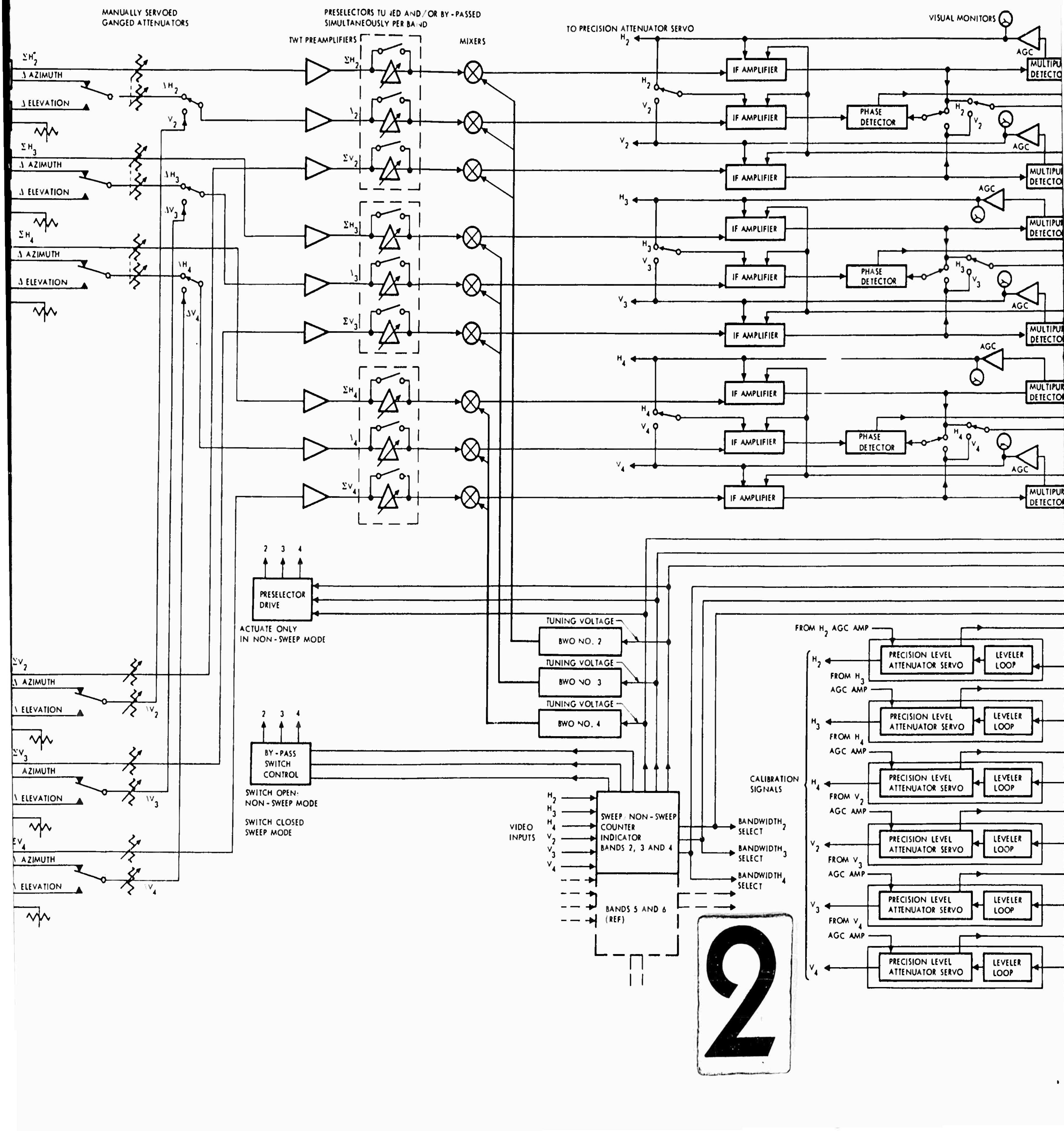


Figure 4.4-2. Block Diagram Indicating the Panoramic Receiver Configuration for Band 1



CALIBRATE/OPERATE SPDT SWITCH ARRAY
SUM AND DIFFERENCE HYBRID ARRAY
MANUALLY SERVOED GANGED ATTENUATORS
TWT PREAMPLIFIERS
HORIZONTAL POLARIZATION
1-2 GCS BAND 2
2-4 GCS BAND 3
4-8 GCS BAND 4
AZIMUTH
ELEVATION
CALIBRATION SIGNALS
PRESELECTOR DRIVE
ACTUATE ONLY IN NON-SWEEP MODE
VERTICAL POLARIZATION
BY-PASS SWITCH CONTROL
SWITCH OPEN: NON-SWEEP MODE
SWITCH CLOSED SWEEP MODE

1


MANUALLY SERVOED GANGED ATTENUATORS
PRESELECTORS TUNED AND/OR BY-PASSED SIMULTANEOUSLY PER BAND
TWT PREAMPLIFIERS
MIXERS
TO PRECISION ATTENUATOR SERVO
VISUAL MONITORS
AGC
MULTIPURPOSE DETECTOR
IF AMPLIFIER
PHASE DETECTOR
AZIMUTH
ELEVATION
PRESELECTOR DRIVE
ACTUATE ONLY IN NON-SWEEP MODE
TUNING VOLTAGE
BWO NO. 2
BWO NO. 3
BWO NO. 4
BY-PASS SWITCH CONTROL
SWITCH OPEN-NON-SWEEP MODE
SWITCH CLOSED SWEEP MODE
VIDEO INPUTS
SWEEP NON-SWEEP COUNTER INDICATOR BANDS 2, 3 AND 4
BANDS 5 AND 6 (REF)
CALIBRATION SIGNALS
BANDWIDTH 2 SELECT
BANDWIDTH 3 SELECT
BANDWIDTH 4 SELECT
FROM H2 AGC AMP
FROM H3 AGC AMP
FROM H4 AGC AMP
FROM V2 AGC AMP
FROM V3 AGC AMP
FROM V4 AGC AMP
PRECISION LEVEL ATTENUATOR SERVO
LEVELER LOOP
2

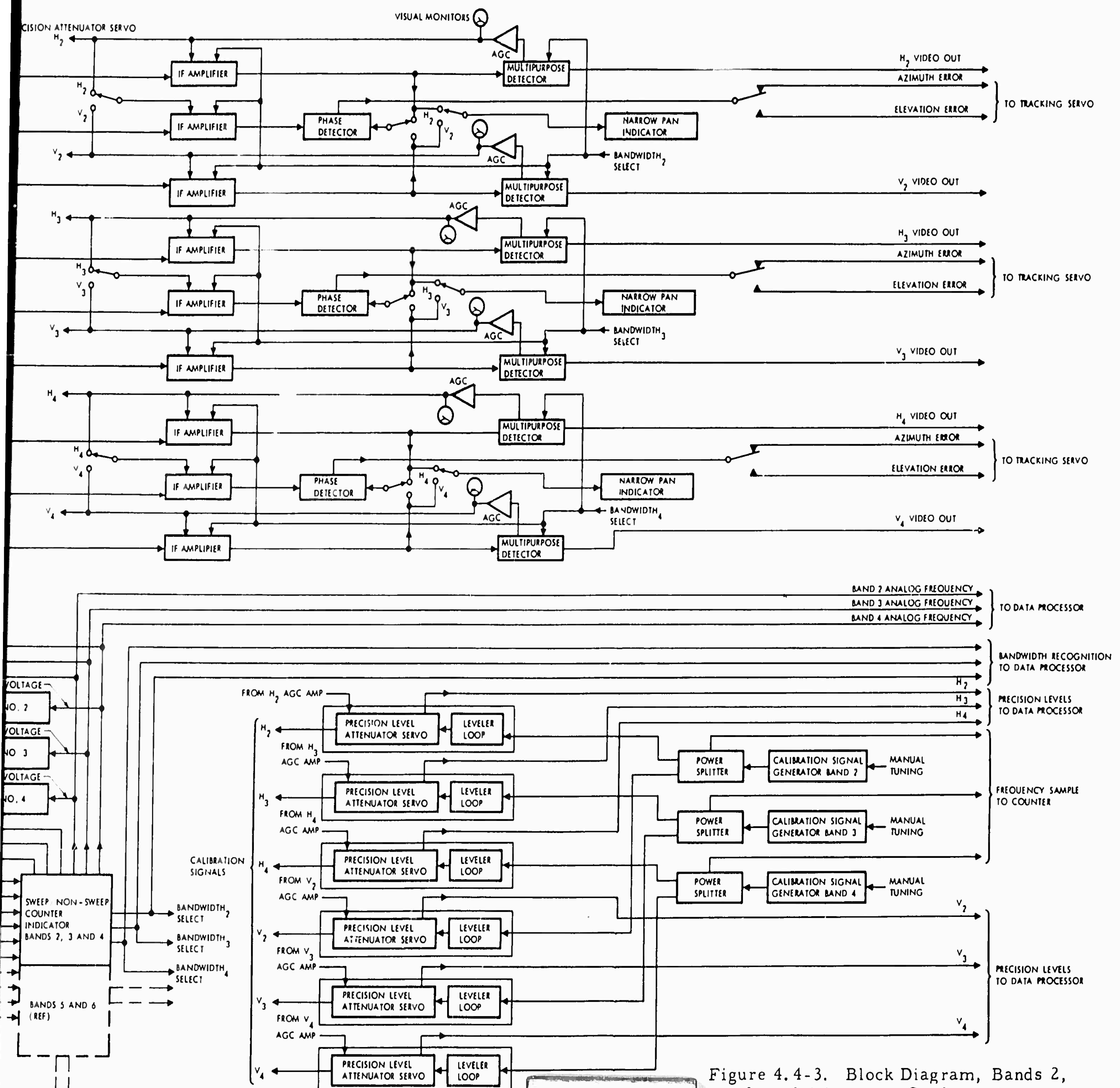
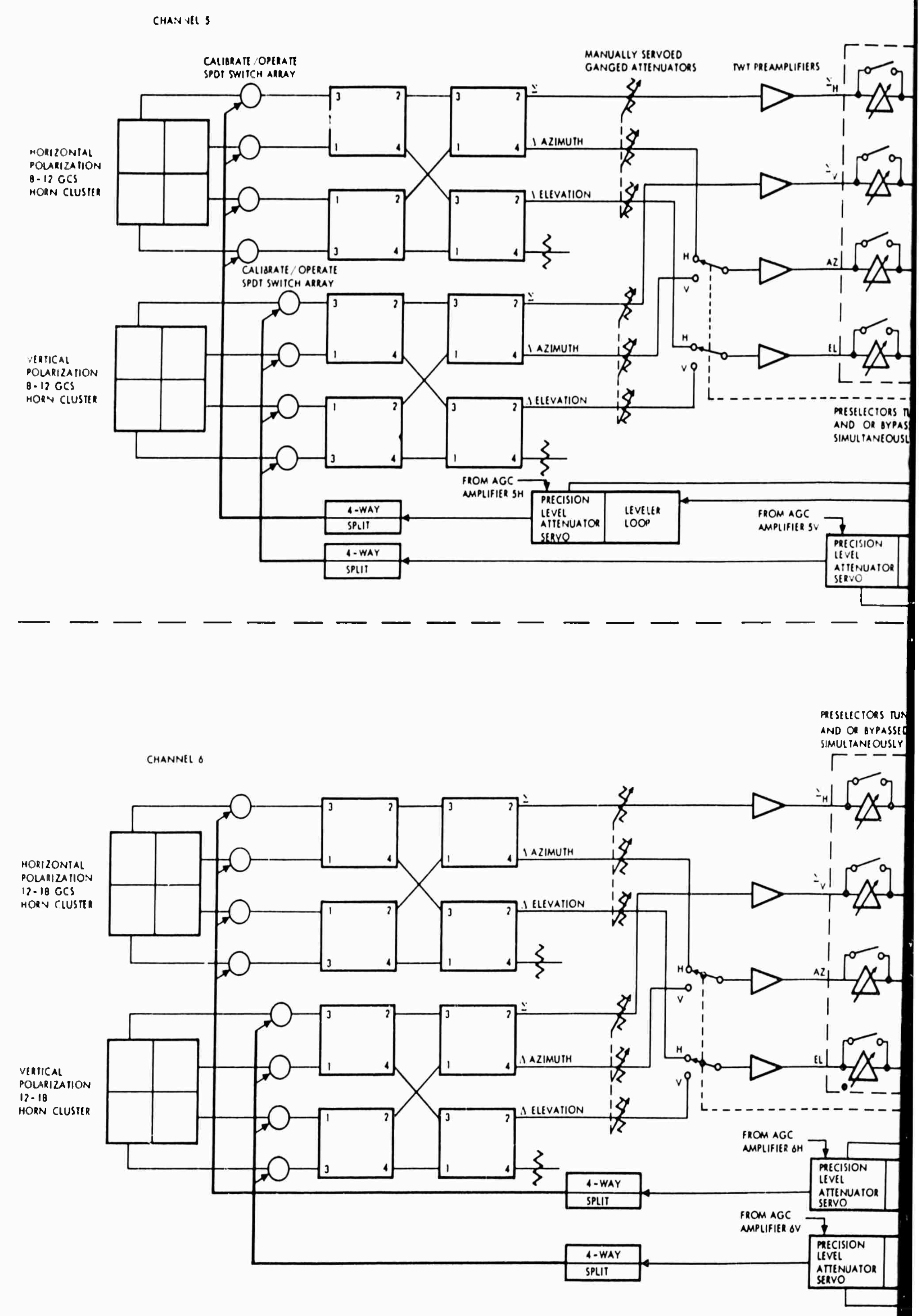


Figure 4.4-3. Block Diagram, Bands 2, 3, and 4 Receiver Configuration


CHANNEL 5
CALIBRATE/OPERATE SPDT SWITCH ARRAY
HORIZONTAL POLARIZATION 8-12 GCS HORN CLUSTER
VERTICAL POLARIZATION 8-12 GCS HORN CLUSTER
MANUALLY SERVOED GANGED ATTENUATORS
TWT PREAMPLIFIERS
AZIMUTH
ELEVATION
PRESELECTORS TU AND OR BYPASS SIMULTANEOUSL
FROM AGC AMPLIFIER 5H
PRECISION LEVEL ATTENUATOR SERVO
LEVELER LOOP
4-WAY SPLIT
FROM AGC AMPLIFIER 5V
CHANNEL 6
HORIZONTAL POLARIZATION 12-18 GCS HORN CLUSTER
VERTICAL POLARIZATION 12-18 HORN CLUSTER
PRESELECTORS TUN AND OR BYPASSED SIMULTANEOUSLY
FROM AGC AMPLIFIER 6H
FROM AGC AMPLIFIER 6V

1

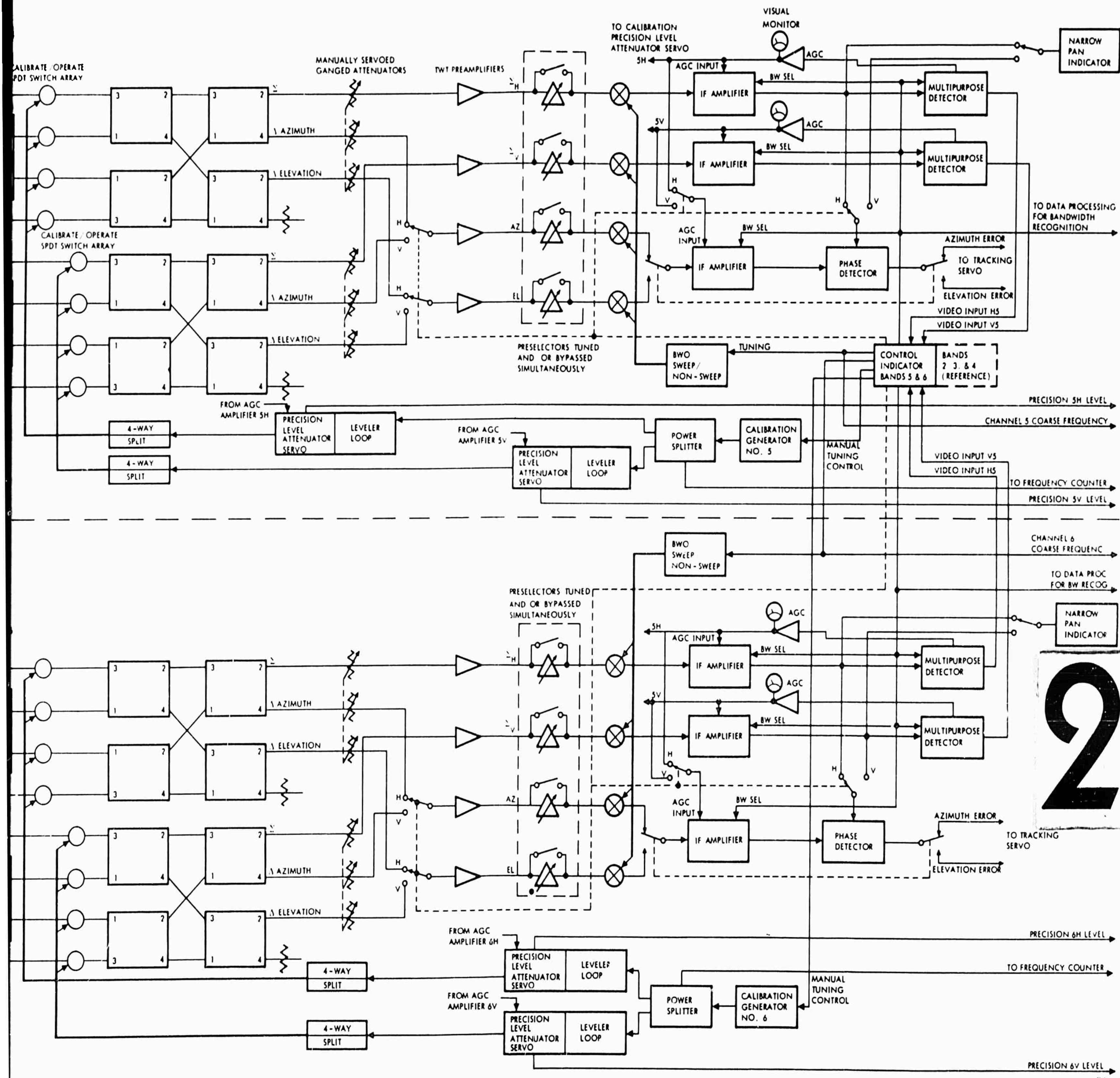


Figure 4.4-4. Block Diagram, Band 6 Receiver Configuration

To this end, it is recommended that the Band-1 receiver should not be operated in both the swept and fixed modes, but rather that the panoramic function be made separate from the non-sweeping receiver. This is shown in Fig. 4.4-1 accordingly. The first LO's of the three non-sweeping receivers are sampled for presentation on the Panoramic Receiver to assist the operator. This is accomplished through the auxiliary mixers #3 and #4 of Fig. 4.4-2.

Inasmuch as the auto-track function cannot respond to more than one signal at a time, and further, that this signal will favor one polarization, it is obvious that only one Δ channel is needed. Once the signal reaches the first i-f, it is possible to take advantage of this fact. Figures 4.4-1, 4.4-3 and 4.4-4 show 8 individual Δ channel i-f amplifier and phase-detector circuits, one for each of the bands 1A, 1B, 1C, 2, 3, 4, 5, and 6 wherein the AZ and EL error signals are time shared. Seven of these are superfluous; they are shown only for functional clarity. Figure 4.4-5 shows the composite Δ channel configuration that actually applies. With careful design, differential phase shifts for all bands can be made zero at band centers. Zero differential path lengths can be very nearly realized by block construction of all r-f assemblies within each band. Any residual phase differences may be corrected by maintenance personnel, using the phase vernier control.

The injection of the calibration signals before the Band Separation Filters of Band 1 was made desirable by virtue of the fact that three calibrate signals (one in each band segment) may be required at any one time. The use of a single switch in front of the filters requires that the calibrate-signal port be fed from a coaxial signal adder. Such a device has a minimum insertion loss of 4.8 db employing tapered coaxial impedance transformation, which is actually a three-way equal-power divider used in reverse. In Band 1, the tracking preselectors, L.O.'s, i-f's, etc., that is, everything following the wide-band/low-noise preamplifiers and multicouplers, constitute six separate, manually tuned receivers, three for the horizontal sum channels A, B, and C, and three for the vertical sum channels A, B, and C. The Σ and Δ mixers must have common local oscillators. This can be achieved by modification of currently available equipment.

The variable attenuators preceding the preselectors and preamplifiers are ganged so as to maintain the Σ/Δ ratio constant for H and V separately for each band. This is made necessary by the monopulse tracking requirements on amplitude and phase. These attenuators are used to reduce the levels of large input signals so as to avoid overloading their AGC loops.

Because Band 1 incorporates a separate Panoramic Receiver, the preselector function required by the non-sweeping receivers must not precede the low-noise preamplifiers and multicouplers. This means that the dynamic range of these preamplifiers must be slightly greater than the overall system specification because non-linearity due to overload in the preamp produces cross-modulation. For complete freedom from interference of this type by very large unwanted signals, the amplifier must be linear up to its overload level which should be at least -10 dbm.

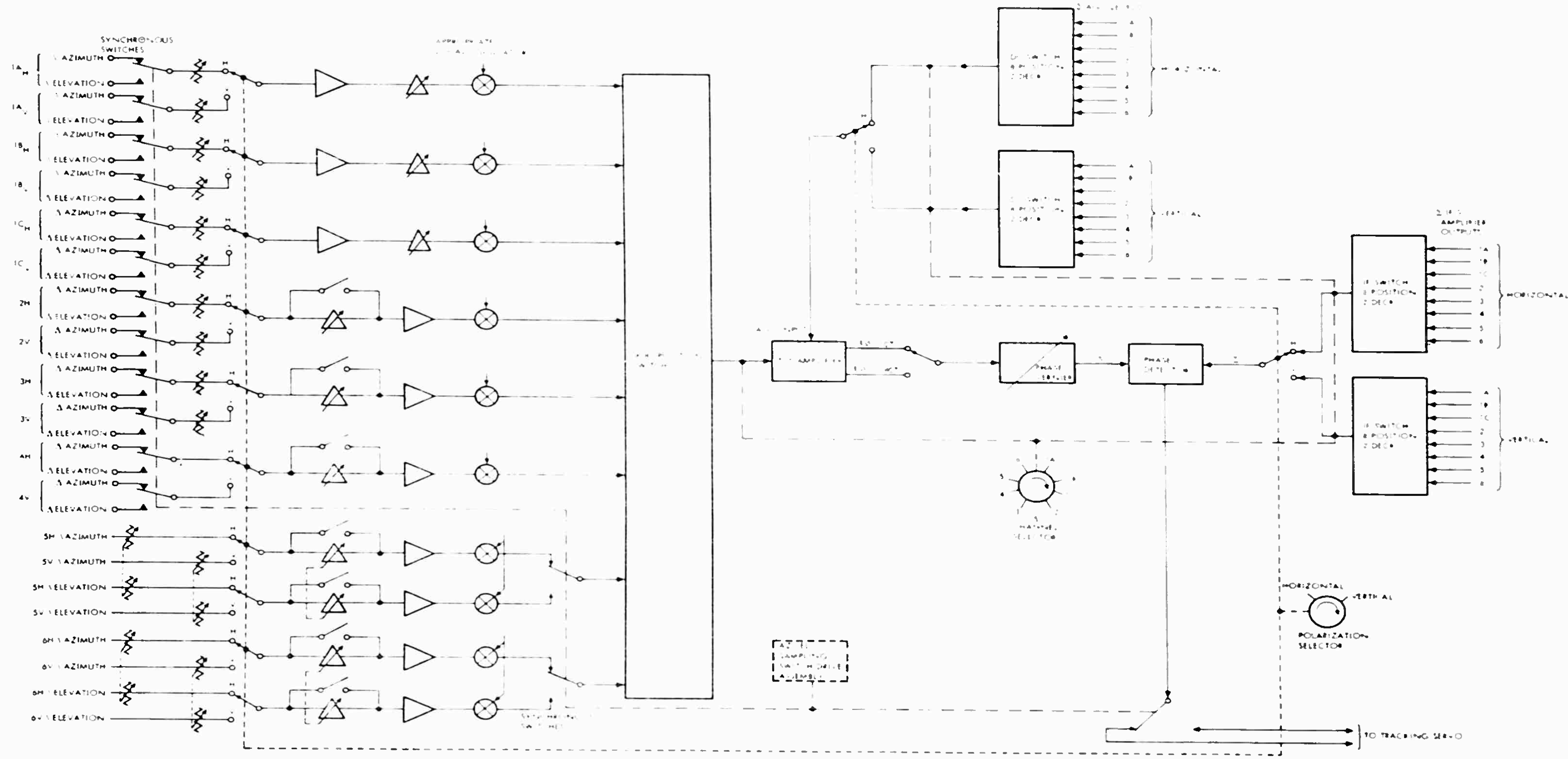


Figure 4.4-5. Block Diagram Indicating the Passive Tracking Configuration for All Bands

Table 2.4-2 of Sec. 2.4.1 tabulated the calculated receiver noise figures for each band. These calculated noise figures were based upon data obtained from various manufacturers as to the achievable noise figures of available wide band amplifiers and an estimate of the various r-f losses. The noise figures given for the three tunnel diode amplifiers employed in the Band 1 receiver were obtained from Micro State Electronics Corp., Murray Hill, New Jersey. The noise figures for the TWT amplifiers employed in the remaining Bands 2 through 6 were obtained from the following data supplied by Watkins-Johnson, Palo Alto, California.

TWT Model No.	Frequency Range	N.F.	Gain
WJ-278	1 KMc - 2 KMc	4.5 db	28 db
WJ-269	2 KMc - 4 KMc	5.6 db	28 db
WJ-271	4 KMc - 8 KMc	5.5 db	28 db
WJ-276	8 KMc - 12 KMc	7.5 db	28 db
WJ-257	12 KMc - 18 KMc	9.0 db	25 db

The anticipated r-f losses between the sum signal output from the antenna include the loss in the calibration switch and any transmission line losses. In addition, the three Band 1 sub-channels must include an additional loss in the band separation filter. These losses are estimated to be 2 db for the sum of switch loss plus transmission line loss and 4 db when the expected filter is included for Band 1.

It should be noted that the resulting S/N = 1 sensitivities tabulated in Table 2.4-2 are for the sum channel only, which is employed for signal amplitude measurements as well as part of the passive tracking system. The difference channel can be expected to have 1 db less sensitivity due to the additional switch to commutate between the azimuth and elevation difference signals. This will not effect the system operation, due to the very low bandwidth of the system during passive tracking. The servo system acts as a low pass post-detection filter, which affords considerable improvement in signal-to-noise ratio ($\approx$ 30 db) for signal-to-noise ratios greater than unity. This improvement deteriorates as the pre-detection S/N drops below unity; however, as indicated in the range calculations of Sec. 2.1, more than adequate performance is available.

The two highest Bands, 5 and 6, are arranged differently in the area of r-f processing. Commutation of the AZ and EL channels is not done until after the first mixer. The problem here is due to the lack of currently available r-f switches exhibiting SPDT action with equal and constant path lengths. The duplexer type of switch described in Sec. 2.4 and shown in Fig. 2.4-4 may exhibit phase errors due to variations in the dual switch when in the "shorted" condition. Should development indicate that the path lengths are constant even though not equal, then the configuration of Bands 2 through 6 could be identical.

The mixers in Bands 2 through 6 should be of the SSB type so as to take advantage of the 20 to 30 db image suppression available in this configuration.

The maximum bandwidth of each channel shall be determined by the i-f amplifiers. The r-f preselectors shall be narrow enough to guarantee image rejection but always wide enough to avoid BW restriction. Band narrowing may then be done by switching in appropriate filters in the i-f amplifier and, if FM video is being recovered, selecting the correct discriminator. Maximum available gain shall change with BW so as to maintain a constant noise level at the detector input when the AGC loop is inactive due to the input signal being at or below the AGC threshold. Various weighting factors will be applied to the AGC detector output to accommodate the range signals expected. A BFO will be included to monitor CW signals.

One Narrow Panoramic Monitor is provided for each band and subband; either the H or the V signal is selected manually by the operator. The purpose of the monitor is to give an indication of signal drift and to automatically generate an alarm when the drift has exceeded preset limits, which should be continuously variable from ± 10 Kcs to ± 1 Mcs. The presentation on the monitor's scope will show both the incoming signal and the calibration generator sample with vertical deflection upward for S_1 and downward for S_2. This gives a convenient check of the calibration generator tuning accuracy.

4.5 DATA PROCESSOR

The purpose of this Technical Discussion is to describe a means whereby the instrumentation data from the wide-band passive tracking system may be transferred under control of the operational program to an on-line digital computer for processing. The processed data will then be stored on either paper tape or magnetic tape. Quasi-real-time data (computer parameters) will be recorded on the digital plotter.

The Data Processor subsystem is designed around the AN/UYK-1 Digital Computer thereby incorporating the flexibility and expansibility inherent in a digital device of this type. This will readily permit program changes that may be required to meet current and future mission requirements.

Data formats are generated and controlled by the computer and therefore any changes in the input data format will normally require only slight computer program modifications.

The typewriter, in addition to providing results of computer diagnostic tests, can be used to actively provide communication between the system operator and the digital computer. For instance, during active test runs the operator could command the computer operational program to type specific data values and thereby provide a means to visually monitor the test in progress.

The operator may also communicate to the computer specific test parameters or evaluation data for storage with the collected test data.

4.5.1 Data Processing System Description.

4.5.1.1 Operational Objectives. - The On-Line Data Processor accepts data in digital form from the Wide Band Passive Tracking System and transfers the data to the AN/UYK-1 Digital Computer. The data are processed in the computer by means of a very flexible operational program. The resulting new parameters are then recorded on a graphic plotter and stored on punched paper tape, or optionally on magnetic tape.

4.5.1.2 System Organization. - The organization of the Data Processor subsystem is illustrated in the system Block Diagram of Fig. 4.5-1. The system is composed of the following elements:

a. AN/UYK-1 Digital Computer.

b. Digital Interface Buffer.

c. Computer peripheral equipment including the TRW-151 Paper Tape Reader, the TRW-161 Paper Tape Punch, and the TRW-185 Typewriter.

d. Two-Axis Digital Plotter.

e. Optional TRW-192 Magnetic Tape Controller and TRW-170 Magnetic Tape Unit.

The Digital Interface Buffer provides the selection circuitry, multiplex address and timing control to effect efficient communication between the computer and the Data Acquisition equipment.

The selection and transfer of data from the Data Acquisition equipment to the computer system is provided under computer operational program control with complete flexibility in sequential or random order and rate of channel selection.

Selected data is transferred to the Digital Computer for further processing and storage. The acquired data are processed as per the specified logical operations in the operational program. The selected data and/or the newly computed parameters are then stored in the computer core memory for later block transfer to the Paper Tape Punch (optionally the Magnetic Tape Unit). The newly computed parameters are further presented as a graphic display on the Digital Plotter, and/or recorded on the TRW-185 Typewriter for visual monitoring.

A brief functional description of the on-line Data Processor is discussed in the subsequent paragraphs to provide a basic understanding of system operations.

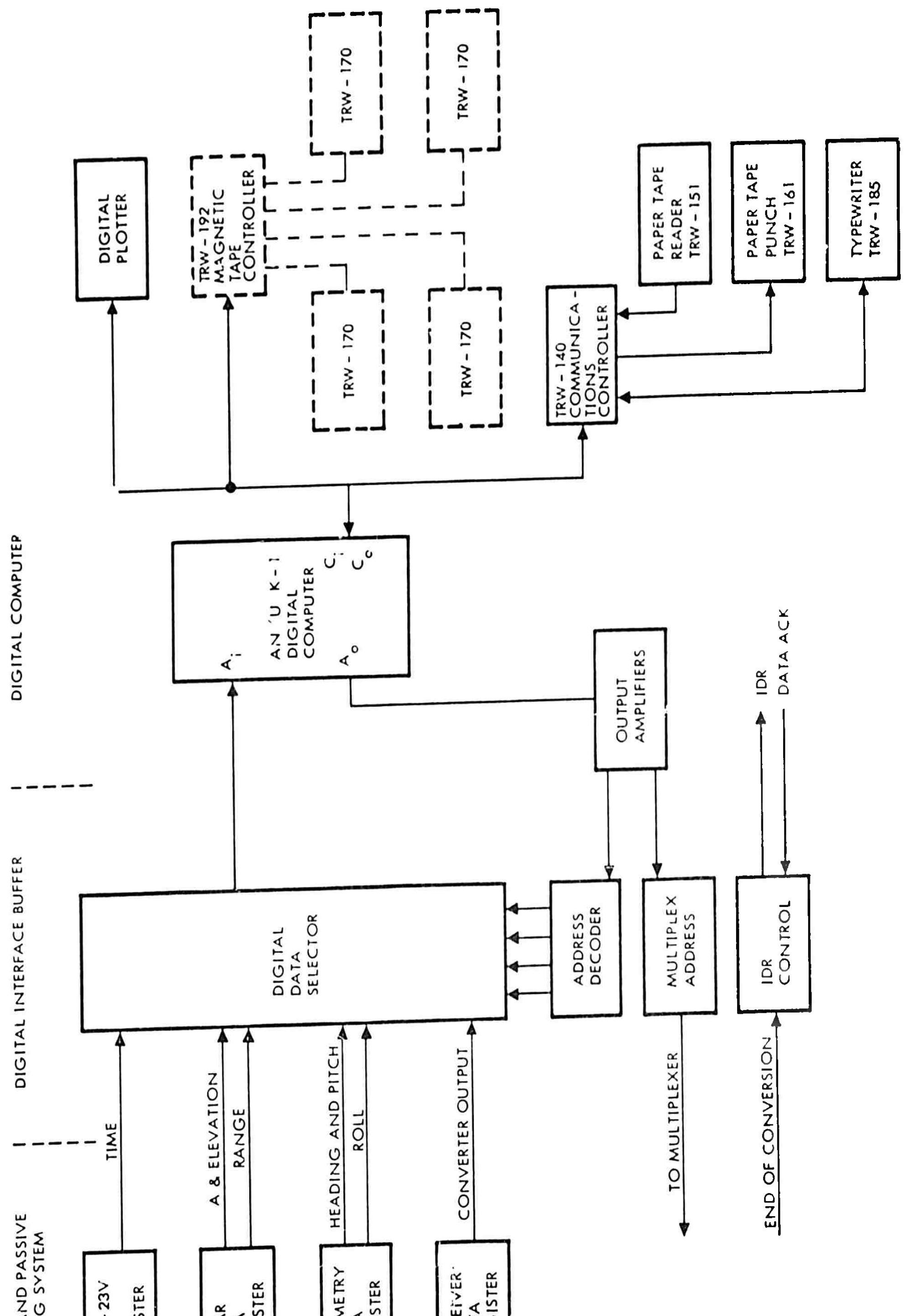


Figure 4.5-1. Data Processor Subsystem Block Diagram

4.5.2 Functional Description. - The subsystem functions in three modes of operation:

Pre-test

Test Zone

Post-test

The Pre-test mode encompasses acquiring 20 bits of time data on one-second intervals and 14 bits each of azimuth, elevation and range data at a five-pps rate. This data is collected and stored for a period of approximately sixty (60) seconds. At this point in time the vehicle will have approached the Test Zone area. The computer having kept elapsed time periods will then revert to the Test Zone program.

During the Test Zone mode the computer will acquire the largest volume of data. In addition, the periodic time and radar data from high frequency receivers and telemetry data regarding aircraft attitudes (Heading, Pitch and Roll) are transferred to the digital computer under operational program control. Also, receiver analog data (horizontal and vertical polarization magnitude) are multiplexed and converted to digital values under operational program control.

The collected data are processed and then new parameters (aspect and depression angles) are computed and stored in the computer core memory.

Upon receipt of five (5) complete groups of data during the test mode (five time periods or one second), the computer program will then enter the Post-test program.

The Post-test mode is approximately sixty (60) seconds in duration and serves a two-fold purpose:

1. it provides an additional check on the heading flown by the aircraft during the test run, and

2. it provides a receiver calibration period.

The collected data during this period consists of:

1. the periodic time and radar data (azimuth, elevation, and range),

2. ten digitized magnitude values of the horizontal polarization signal from receiver No. 1,

3. ten digitized magnitude values of the vertical polarization signal from receiver No. 1.

During subsequent fifth-second intervals, periodic time and radar data followed by receiver No. 2 calibratior data are transferred to the computer until all six (6) receivers have been calibrated. The system then reverts back to only transferring to the computer periodic time and radar data for the remainder of the sixty (60) second time interval.

Meanwhile, concurrently or following the Post-test mode the operator has transferred to the digital computer by means of the TRW-185

Typewriter, specific frequency data for each receiver and abbreviated operation status or receiver data evaluation.

During the turn-around period, all collected data are retrieved from the computer core memory in proper order, formatted and transferred to the TRW-140 Communications Controller for subsequent recording on the TRW-161 Paper Tape Punch.

The collected data and the new computed parameters may be outputted to the plotter if the computed parameters fall within predetermined bounds; otherwise the data may be stored until such time as ordered into the appropriate predetermined antenna pattern plot.

Concurrent with data acquisition and processing specific data may, under program control and appropriate command from the typewriter, be outputted to the typewriter to provide a monitor of the data being collected and processed.

Although the data rates are such that all collected and computer data can be recorded on punched paper tape during turn-around, magnetic tape can also be used as the recording medium with considerably greater capacity and at a higher recording rate. Both types of recording media will be described in subsequent paragraphs.

4.5.3 Computer Programs.

4.5.3.1 Operational Program Description, Data Input. - A fixed programmed sequence of data input is initiated upon receipt of an interrupt signal indicating the start of the Pre-test period. Subsequently, timing signals will be generated from an external clock every 200 milliseconds. Receipt of the timing signal will cause the computer program to initiate the data transfers required. All data transfers in will be selected under program control with the exception of the data input from the typewriter or control panel intervention. For each timing signal interrupt (each 200 milliseconds) the computer will select the appropriate source of input data to be transferred. This will be accomplished by means of an External Function command (EF) which generates a command word over the data lines designating a digital data work address. This will be followed by a Word-In command (WI). Upon the subsequent receipt of an Interrupt Data Request (IDR), the word will then be transferred into core memory. The computer will then issue a Data Acknowledge signal.

The computer will select data words for each 200-millisecond period for the Pre-test, Test, and Post-test periods. If desired, the sequence of data input, or quantity of data input, could be varied dynamically during real-time operation, by typewriter or control panel intervention (assuming that the appropriate computer logic is prestored for the alternate sequences desired).

Azimuth, elevation, and range data will be received every 200 milliseconds. The computer control of this input will be in the form of a programmed subroutine that operates upon receipt of each timing signal. It is not necessary to input time with each set of data, since the computer can update its own clock item as a part of the subroutine mentioned in the foregoing. The time (and date) may be entered initially through the typewriter or control panel switches and subsequently updated by the timing signals received. At the time of recording, the computer program can generate the time associated with each datum received.

During the one second test period, Heading, Pitch, and Roll of the aircraft, together with Horizontal and Vertical amplitudes for each of the six receivers, must be input. This is in addition to the azimuth, elevation, and range tracking data input required for each 200 milliseconds in the test period of 18 computer words. When the data are formatted for recording or other output, additional items will be generated, i. e., frequency, and a timing label.

Initiation of the test period may be a function of the computer's timing item (updated by external timing signals) or it could be initiated as a result of a special interrupt (Type II) originating outside the computer, i.e., if the computer operator were to depress the Momentary Interrupt button on the Operation Control Panel.

During the Post-test period the calibration data will be received from each of the 6 receivers. Up to 6 values of horizontal amplitude and 6 values of vertical amplitude will be received from each receiver. It is expected that the calibration data will be received in the first six (6) 200-millisecond periods of the Post-test period. The number of receiver calibration steps is variable and may be specified as an input parameter either before each run or during the Pre-test period. The computer time required for the input of data is a very small percentage of total available time, leaving the computer relatively free for other computational requirements. It would be possible, therefore, to increase the data input requirements substantially in this application, should future system requirements demand.

4.5.3.2 Computation Requirements. - The computations in the Pre-test period required of the computer program are:

1. Grey to binary conversion of input values.

2. Tracking (smoothing) of aircraft position.

3. Formatting of data for block recording.

These functions will be computed throughout the entire test, including the turn-around phase if desired.

For the test period of one second, the computation of aspect angle and depression angle originating at the aircraft position is based on the additional inputs of Heading, Roll, and Pitch. An averaging of the 5 sets of input parameters during the test period is assumed. A coordinate conversion from polar to rectangular coordinates is required to process the data values to be plotted. The plotting of the data will begin immediately after the processing of the calibration data received in the Post-test period.

The computational requirements as summarized in Table 4.5-1, wherein time and storage estimates are made for the logical segments of the processing programs, indicate a compute utilization factor of approximately 10 percent during the Pre-test and Post-test periods and approximately 30 percent during the Test period.

TABLE 4.5-1

COMPUTER PROGRAM STATISTICS SUMMARY

	PRE-TEST	TEST	POST-TEST	EXECUTION TIME (milliseconds per 200 millisecond interval)	STORAGE MEMORY CELLS PROGRAM	STORAGE MEMORY CELLS DATA	COMMENTS
INPUT							
Time	X	X	X		20		May be as often as desired or set initially only
Az, El, and Range Data	X	X	X	.2	20	1815	
Fitch, Roll, Heading		X		.2	20	15	
Horizontal and Vertical Amplitudes		X		1.0	50	80	
Calibration Data			X	1.3	80	176	For six 200 millisecond periods, only
COMPUTATION							
Grey to binary code conversion	X	X	X	.5	80		
Tracking equations	X	X	X				
Coordinate conversion				12.0	140		
Smoothing				3.0	120	30	
Formation of data-pre-test	X			.5	40		
Computation of Aspect Angle and Depression Angle		X		25.0	360		Computations as outlined in "Determination of the R-F Vector Emanating from an Air-borne Transmitting Angenna"
Formatting of data-test		X		2.0	40		
Formatting of data-post-test			X	1.0	40		
Code conversion for typewriter output			X	2.5	80		
Code conversion for plotter output			X	3.0	40		
RECORDING							
Raw data with associated time item							
Coordinates of aircraft throughout flight				60 char/sec			To be recorded during the time interval while the aircraft is maneuvering for the next approach.
Computed values and intermediate results							

4.5.3.3 Recording. - The recording of all raw data together with the result of all computations, formatted as desired, will take place after the Post-test time period during the interval between successive flights through the area of interest. The recording could be accomplished concomitantly with the data collection, formatting and other computation; however, a simpler solution, requiring less complex control logic, would be to relegate the recording function to a time period which will not conflict with other Input/Output operations.

The data recorded may be selected data or if desired, a complete output of all raw data, together with the results of all computations. It will also include other items which may be required to be generated associated with discrete block of data, such as the timing item (computer clock item), and other data dictated by real-time input during the current input (typewriter or switch input) and any other items that may be useful for off-line analyses.

4.5.3.4 Real-time Output. - In addition to a complete recording of the run on punched tape, selected data will be output in real-time in the form of plotted and printed data. The selection of data may be programmed as a fixed part of the computer program to provide a continuous indication of system performance to monitoring personnel. An additional flexibility is achieved with the use of operator requests for the output of specific parameters from computer storage which would supplement the hard copy record.

4.5.4 Equipment Description.

4.5.4.1 Digital Interface Buffer. - The Digital Interface Buffer is comprised of the following five elements (See Fig. 4.5-1).

a. A set of output amplifiers to accept bits of the computer output to set the selector address decoder register and the multiplex address register.

b. The Selector Address Decoder which consists of a flip-flop register to hold the selected address and a diode decoding matrix to decode the address into the control lines for selection of the designated input lines.

c. The Digital Data Selector which consists of diode logic transfer gates to gate a selected input to the input of the computer.

d. The Multiplex Address Register which consists of flip-flop register to hold the selected multiplex address to provide control lines for receiver data selection.

e. The Input Data Request Control which consists of the control flip-flops to recognize the end-of-conversion signal from A to D converter in the Data Acquisition devices and generates the data request signal for computer input control. It also provides the data request signal and timing for transfer of data into the digital computer.

The periodically sampled data is stored in parallel registers in the Data Acquisition System at logical levels compatible to the diode gating structure of the Digital Data Selector Unit. The transfer of data is normally inhibited and data will be transferred only when an associated control line enables that particular group of gates. There will be one control line associated with each data word to be transferred with control being effected by the Address Decoder.

The Digital Data Selector will be implemented with standard LV logic modules, TRW part no. 40021176.

The Selector Address Decoder accepts a digital word from the AN/UYK-1 Digital Computer via the output cable "A" and the output amplifiers. The digital word corresponds to the address of the data word to be transferred to the computer. The logical states of the address register containing the digital word is decoded and the control line to the Selector corresponding to the desired word is energized, thereby enabling the transfer gates of the Selector Unit. The standard modules utilized in this unit consist of Delay Flip-Flops, TRW part no. 40015168 and Decode logic cards, TRW part no. 40021112.

The analog function data (Vertical and Horizontal polarization) from the six (6) receivers must first be converted to a digital value before transfer to the computer. An addressable multiplexer and an A to D converter are located with the Data Acquisition equipment. To effect random selection and data transfer, the computer places a digital word in the Multiplex Address Register. The Multiplexer responds to the address by sampling the proper function and initiating the A to D conversion cycle. Completion of the conversion generates a signal which will set a flip-flop (IDR control) with the subsequent generation of the Input Data Request to the computer. The computer recognizes the IDS and issues an External Function to the Address Decoder which then energizes the desired control line, thereby enabling the transfer of the digitized analog data word to the computer.

Acceptance of an input data word will cause the computer to issue a data acknowledge signal which will reset the IDR control flip-flop.

The Multiplex Address Register and the IDR Control are implemented largely by standard delay flip-flop modules, TRW part no. 40015168.

To prevent degradation of the analog data due to finite time delays in conversion and data transfer and to permit sufficiently accurate time correlation, the analog data is selected and digitized shortly after the occurrence of the sampling pulse.

4.5.4.2 AN/UYK-1 Computer.

General.

The TRW-developed AN/UYK-1 Stored Logic Multiple Purpose Digital Computer is proposed for this system because of its suitability to the system requirements. Simplicity of operation and ease of maintenance are important features of the equipment. In addition to multipurpose capabilities which make it easily adaptable to system requirements, the computer has the advantage of adaptability to system expansion. A block diagram of the AN/UYK-1 Computer is given in Fig. 4.5-2. Some of the salient features of the computer are:

Physical Characteristics

1. Rugged— developed for shipboard or land based used to withstand shock, vibration, moisture and other adverse environments.

2. Small—occupies little space and is easily transportable—57 inches high, 20 inches wide, and 14 inches deep.

3. Human Engineered—all maintenance and control features readily accessible from the front.

Economic Features

1. Low Cost—basic unit is in the low price range.

2. Multipurpose—easily adpated to general purpose or special purpose applications.

3. Expandable—basic memory element can be expanded by factor of four.

4. Programmable—simple, flexible, yet compact programming techniques permit maximum use of programming and computation time

5. Flexibility—permits use of a wide variety of input-output devices at minimum cost.

Description.

Principal functional equipment groups are shown schematically in Fig. 4.5-3. A description of each follows.

Core Memory

The initial core memory has storage for 8192 15-bit words. A matrix switch is provided for selecting one of 8192 addresses. Fifteen inhibit drivers and four timing generators are provided.

Control Flip-Flops and Input/Output Control Logic

A set of Control Flip-Flops are provided for Input/Output Controls and internal control and timing. The computer also includes control logic and special circuits for input/output functions.

Clock Generator

The computer clock rate is 333 Kc per second; the memory read-write cycle requires six microseconds.

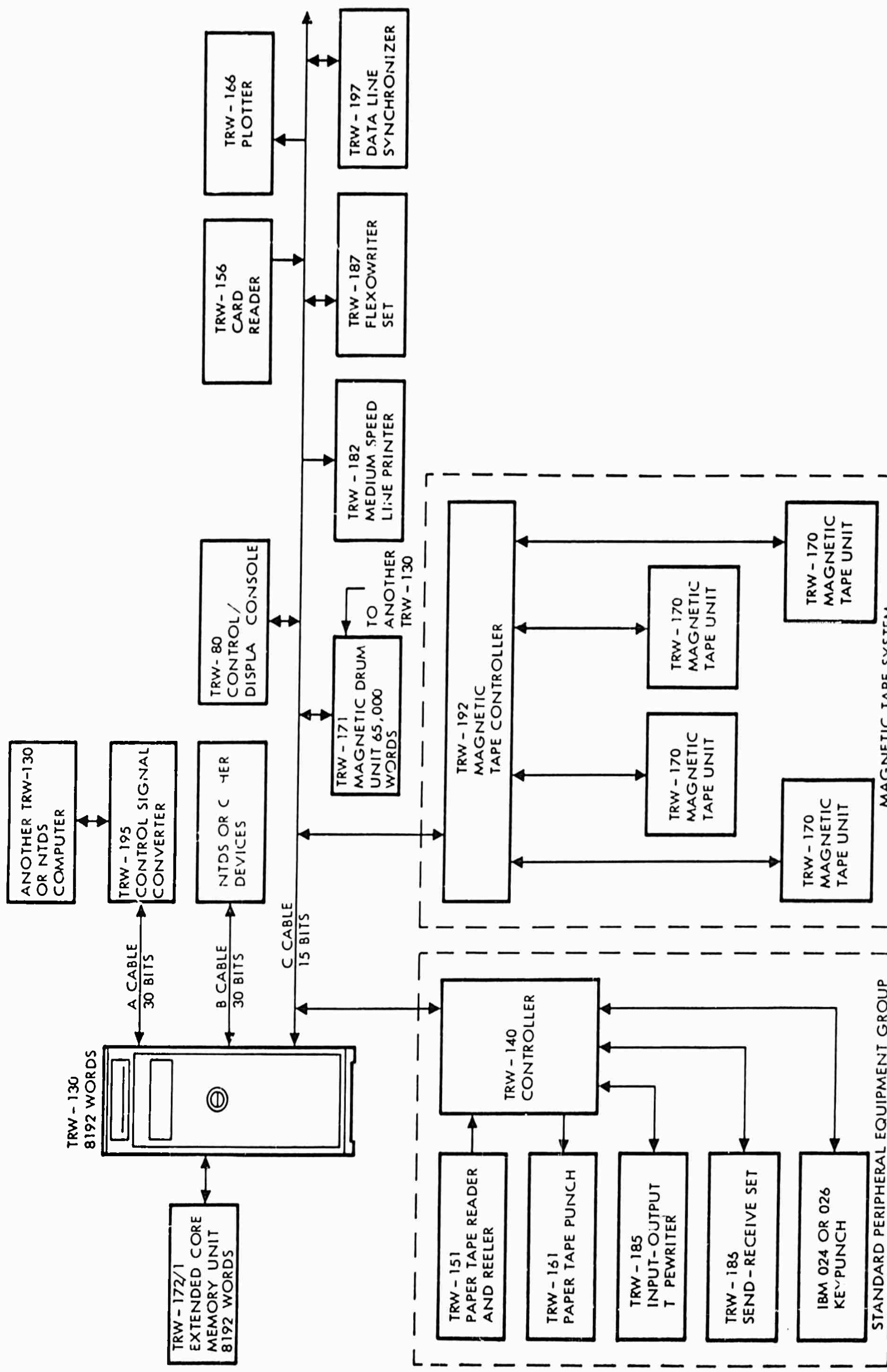


Figure 4.5-2. AN/UYK-1 and Peripheral Equipment

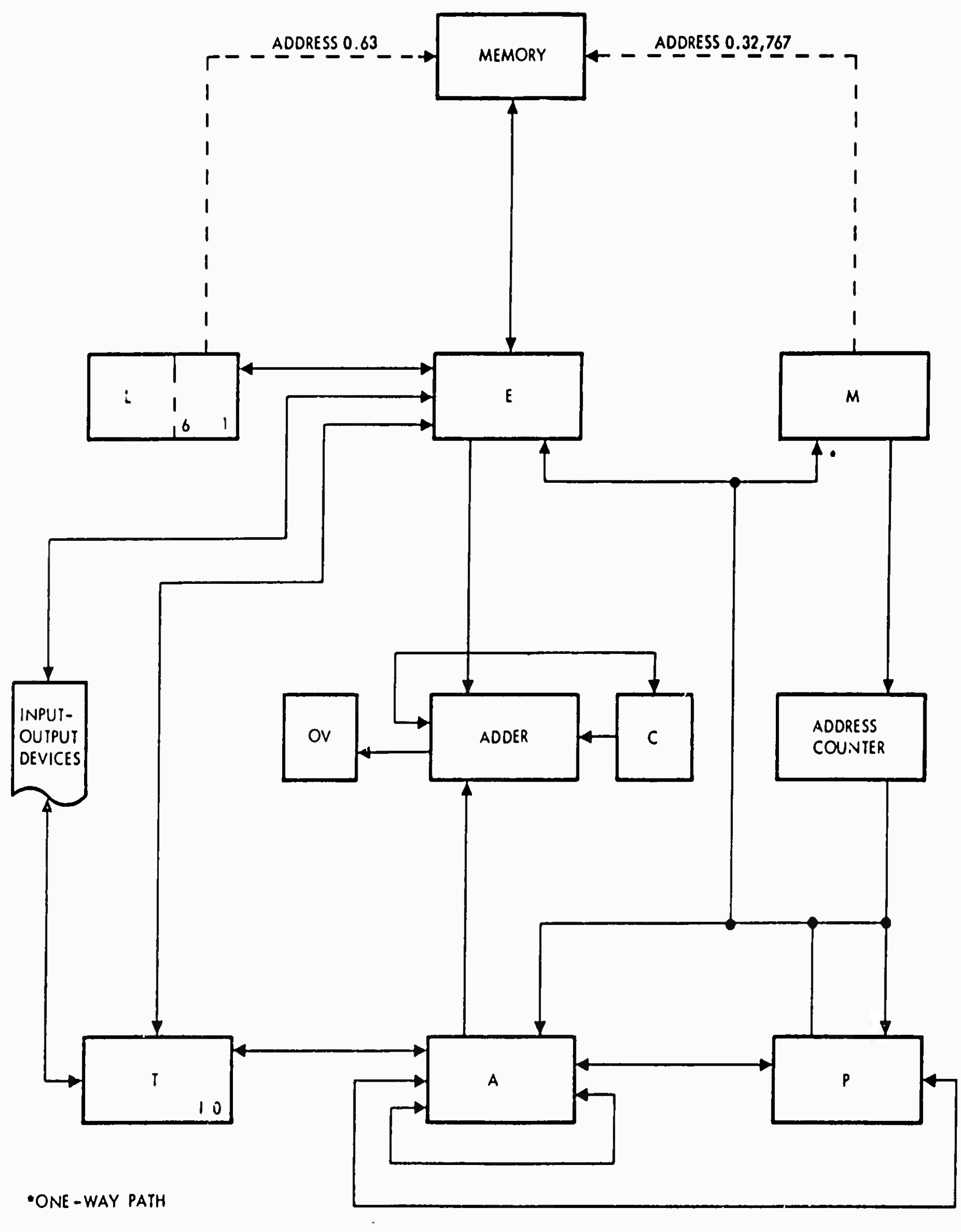


Figure 4.5-3. Logical Organization

Registers

The computer includes six fifteen-bit flip-flop registers for all internal data processing and handling:

1. L-Register—Contains the logand being executed. A portion of the L-Register can address a small part of the core memory. Accepts transfer from E-Register.

2. E-Register—Communicates with the core memory. Accepts transfers from cores, from the A-, P-, L-, and T-Registers.

3. M-Register—Addresses the core memory, and is also used for storage in arithmetic operations. Accepts transfers from E-, A-, or P-Registers. The source of counting transfers to A- or P-Registers.

4. P-Register—Accepts transfers from M-, E-, and A-Registers, shifts left and right.

5. A-Register—The active accumulator—also used for temporary storage. Accepts transfers from M-, P-, and E-Registers and full adders, clears, shifts left and right, and inverts the contents.

6. T-Register—15-bit input/output buffer register. Accepts transfers from external data lines, A-, or E-Registers. Most internal computer operations can proceed in a regular manner while the T-Register is communicating with slow-speed peripheral equipment.

7. Half-Adder Counter—15-bit register for operational counting transfers. Accepts transfers from M-Register. Transfers to M-, P-, or A-Registers.

8. Full-Adder 15-bit Arithmetic Register—Accepts transfers from E- or A-Registers. Transfers to A-Register.

9. In addition to the active registers enumerated, 64 cells in the core memory may be addressed directly by the logand and may be considered to be auxiliary registers.

Component Parts.

The stringent reliability requirements on the equipment necessitates extensive receiving inspection, vendor qualification, continual requalification and lift test programs at TRW even when military qualified parts are not used. The testing program assures the overall quality of the product, and is tailored to actual equipment requirements. The elimination of duplication of qualification and reliability monitoring effort can materially reduce costs while allowing increased equipment reliability. Field maintainability is assured by unilateral interchangeability with military preferred parts. Any company specified part is readily replaceable with a standard military part in the field in the event of a failure. All schematic diagrams, parts lists, and maintenance manuals refer to the (interchangeable) preferred parts while the TRW parts themselves carry an unambiguous interchangeability designation, e.g., the p n p transistor conforming to TRW Specification Control Drawing 400609 is clearly labeled "replace with 2N428." Manufacturing cost and maintenance cost are thus minimized separately as parts of the reliability assurance program. The cost estimates of this proposal assume deviations from the exclusive use of military approved component parts as necessary to achieve the goals of this integrated reliability-value program.

Circuits.

Only basic circuit configurations that have proven two-year reliability records are used in the computer. Conservative design has made the circuits insensitive to large fluctuations of ambient temperature, supply voltage and component part parameter values. Stress on component parts due to power dissipation and current are extremely mild. Circuit design has been guided by rules requiring ample safety factors; the result is computer circuits which are virtually immune to failures resulting from component part parameter drifts caused by changes in ambient conditions or by aging. The result is an equipment with a reliability approaching the ultimate storage-life reliability of the component parts.

All circuit cards have test connectors at the front of the card for monitoring input and output levels and significant internal points. Logic cards have test points on all gate centers. The circuits used in the AN/UYK-1 are as follows:

1. Set-Reset Flip-Flop—has set and reset inputs and normal and complement outputs. It operates at rates to 700 Kc and drives loads as low as 100 ohms.

2. Delay Flip-Flop—identical to the set-reset Flip-Flop except that it responds to the condition of a single line for both setting and resetting.

3. Control Amplifier—supplies current to activate a group of gates which act in concert.

4. Sense Amplifier—detects the readout of data from the core planes representing one bit at all addresses in the memory core matrix.

5. Core Selection Switch—used to decode address register flip-flops to select one read-write drive line on each of two axes of the memory core matrix.

6. Inhibit Driver—permits writing a "zero" by activating the inhibit winding on the selected core plane to prevent a "one" being written.

7. Pulse Generator—produces an output pulse when the input is true at clock time.

8. Full Adder—accepts addend, augend, and carry. Produces sum and carry.

9. Half Adder—accepts four digits from four consecutive bits of a register, plus a carry, and produces four sum digits and a carry.

10. Clock Generator—an oscillator and pulse shaper which generates a 333 Kc clock of 15 v amplitude, 0.35 µsec wide, and has a rise time of 0.1 µsec.

11. Transfer Logic Card—thirty diodes and 15 resistors logically arranged to effect a complete 15-bit register transfer.

12. Logic Gating Structure—is of the "AND-AND-OR-OR" type using only diodes, resistors.

Input/Output.

The AN/UYK-1 speeds the processing of data by reacting quickly and automatically to external control signals and by providing special logands to manipulate blocks of information.

1. Input/Output Transfer with Slow Speed Devices—The T-Register of the computer is used as the buffer for slow speed input/output device. A number of such devices can be connected for either input or output. Selection of the particular input or output device can be under computer control or under interrupt control by the device. Switching between devices can be accomplished automatically and rapidly. Character inputs to the T-Register can be assembled automatically into full computer words.

   This feature is required for reading in the bootstrap loading program, and may be used with any of the low speed inputs.

2. Input/Output Transfers with Other Devices—Direct communication with the AN/UYK-1 may be had by using specially designed registers to communicate with the T-Register or the E-Register under control of the computer. This permits rapid readout of data for display purposes, D-A conversion, and other similar purposes.

   Peripheral units that can be used with the AN/UYK-1 include, but are not limited to, digital data links, paper tape punches, card readers, line printers, plotters, and data converters.

Operating Features.

The operational controls of the AN/UYK-1 are designed from a human engineering viewpoint to permit rapid learning with minimum effort. The design of the control panel has the following features:

1. Minimum number of controls.

2. Familiar elements (simple toggle and pushbutton switches and indicating lights).

3. Familiar descriptive labels and legends.

4. Logical arrangement.

The controls on the operator's panel are:

1. A power switch (circuit breaker) and indicating light.

2. 15 toggle switches arranged in a row.

3. 15 neon lights arranged in a row to correspond with the toggle switches.

4. A name card holder so that a card identifying specific functions for the switches and lights can be inserted.

5. A pushbutton.

The 15 toggle switches permit manual inputs into the computer. When the pushbutton is operated, the computer is interrupted and the number set into the toggle switches is read into the computer. The function of the toggle switch register is therefore specified by program control. All normal use of the machine including entry of new programs is controlled in this manner.

Maintenance.

The stored-logic approach used in the AN/UYK-1 minimizes the maintenance man's learning task in two ways:

1. It is a parallel machine and parallel arithmetic leads to many repetitions in the physical structure.

2. Only elementary logical operations are implemented with hardware. Complexity is in the logand sequences.

Certain controls are provided exclusively for maintenance purposes in the AN/UYK-1—located behind an access door on the control panel. The maintenance man also uses the operator's controls. The following are on the Maintenance Control Panel:

1. Running time meter.

2. Voltmeter and selector switch.

3. Pushbutton switches for:
   - Single clock
   - Single logand
   - Single sequence

4. Primary mode toggle switches:
   Normal - single step
   Normal - maintenance loading

5. Power supply marginal test switches.

6. Transfer pushbuttons.
   E → L
   Switches → E
   E → A
   E → M
   E → P
   E → T
   Clear core and write E.
   Clear E, read core and rewrite.

7. Test jacks on clock, power supply voltages, synchronization signals, etc.

The controls described are sufficient to provide the capability for complete manual control of all phases of machine operation and flexibility for quick diagnosis of failures.

Every insert card has test points accessible without removing the card. Power supply test points are provided on the Maintenance Control Panel. All test points are immediately accessible when the door of the cabinet is open.

Maintenance data consisting of logical equations, wiring by wire name, wiring by connector, logic diagrams, insert card schematics, power supply schematics, cable connections, etc., provide all information necessary to enable maintenance personnel to isolate a malfunction and replace or repair the defective unit. In addition, a comprehensive set of diagnostic maintenance programs will be provided, including routines for addressing, reading, and loading associated peripheral equipment. Due to the features enumerated, the AN/UYK-1 has a MTTR of less than 15 minutes based on actual field experience.

Summary of AN/UYK-1 Characteristics.

1. Physical Characteristics

   Components - Solid-state

   Size - 13 inches deep, 20 inches wide, 59 inches high

   Environmental Tolerance - General requirement, MIL-E-16500C (Navy)
   Dripproof, MIL STD 108D
   Vibration, MIL STD 167 (Ships)
   Shock, MIL-S-901B (Navy)
   Temperature 0° - 50° C

   Power - 115 volt, 60 cycle, 1000 watts

2. Computer Organization

Operation - Parallel by 15-bit word elements

Word Length - Variable in integral multiples of 15 bits

Order Structure - Variable by stored logic to be single, double, triple or any address structure

Instruction Code - Adapted to the problem

Memory - 8192 word elements random access core
6 microsecond read-write cycle
All operation times include memory access

3. Input/Output

Interrupt - 18 microseconds reaction time
Interrupt subroutine
Automatic return in 18 microseconds to prior task

Buffer Transfer - 18 microseconds reaction time
6 microseconds per 15-bit word element
Automatic return in 18 microseconds to prior task

Block Transfer - 12 microseconds setup time
12 microseconds per 15-bit word element

Available Transfers - 30-bit parallel
15-bit parallel
15-bit serial-external control

4. Operating Speed

Typical Selected Instructions - Operation times include memory access times

	Operation Times (microseconds) Add	Multiply
Single Address		
Direct (15 bit)	12	63
Fixed Point Interpretive (15 bit)	30	93
Triple Address		
Fixed Point (30 bit)	72-150	348-486
Floating Point (45 bit)	240-438	384-570

Table Lookup - 12 microseconds setup
12 microseconds per 15-bit word element

Match - 12 microseconds setup
12 microseconds per 15-bit word element

Branch or Skip - 12 or 18 microseconds

Block Transfer - 12 microseconds setup
24 microseconds per 15-bit word element

4.5.4.3 Programming Method. - The design of the AN/UYK-1 is based on adaptation of the stored logic concept. Much of the control logic that is normally wired into a computer is instead stored as part of the program in core memory. With the use of stored logic, redundant and unneeded hardware can be eliminated in favor of a software design closely tailored to the particular application. Replacement of circuit components with a software package results in reduction of size and weight; and, at the same time, in a more powerful logic structure with increased program flexibility. Stored logic provides for the construction of a problem-oriented software design from basic micro-command building blocks. With these, the user can effectively design an instruction set to suit his own needs. He may specify whatever logical organization (word length, order structure, instruction repertoire) best fits the processing problem at hand.

The language levels available to the AN/UYK-1 user range from the basic machine commands, called Logands, (logical commands), to instructions of an intermediate level of abstraction coded in a symbolic form easily adaptable to the unique problem requirements. This is the Logram (logical program) level, in which instructions of arbitrary complexity are implemented by lograms each of which closely resembles a closed subroutine, and is comprised of a sequence of machine language instructions (logands). The design of the AN/UYK-1 greatly facilitates the linkage between lograms and the accessing of logram parameters, with the result that the special bookkeeping operations normally required in subroutines are not required. A customized instruction set (of lograms) may be designed, tailored to the user's requirements, or, in the case of the typical situation, a select number of special lograms are written to be imposed on a standard logram set.

Such a set is the AN/UYK-1 Standard Logram Set which is delivered to each user. The set includes all the instructions required to program the computer as a general purpose machine in a language most useful for the translation from problem statement to program statement. The extent of these instructions goes beyond the machine vocabulary generally available for conventional computers.

A primary advantage of this technique is to provide the user with a logram set most useful for a particular purpose. The operator may augment or delete lograms from the set as required, and develop special purpose lograms as required.

Available to the AN/UYK-1 user, in addition to the variety of lograms and logram sets, is the option of coding the computer on the basic machine command level. This is occasionally found desirable for certain applications, particularly when execution time is a critical concern. And finally, it is possible to intermix symbolic logram instructions and basic machine code in a single program providing the greatest possible command versatility.

The format of the programming language of the AN/UYK-1 is similar to a one-address computer. For example, to add the contents of a memory cell, noted symbolically as G, to the accumulator, the programmer would write:

AD1 G

In the conventional computer, the above statement would usually reside in a single memory cell. For the AN/UYK-1, AD1 refers to the symbolic address of the first cell of the machine code which will effect an Add, Single Length function. The address of the operand, denoted G, appears in the next cell in sequence after AD1. Therefore, the AN/UYK-1 program code appears in a vertical multi-word format, where each word contains an address.

AD1

G

The first word of a logram calling sequence refers to the logram starting address followed in sequence by the address of the operand(s) required to perform the prescribed function. A slightly more complex logram is:

BBD

This is the symbolic code for a binary to binary-coded decimal conversion. In addition to the one-address format, it is possible to design lograms which expect several input parameters, i.e.. with a multi-address format; or without operands as in this example. The number to be converted is assumed to be in the accumulator upon entry into the BBD logram, and the converted code is placed there before exit from the logram.

The Standard Logram Set provides for single, double, and in some cases quadruple length operation.

Lograms may range in complexity from simple arithmetic, logical, and control instructions found in most instruction sets to special purpose functions that would ordinarily require the operation of a rather lengthy subroutine.

The computer instruction repertoire applicable to the computations required in this application could consist chiefly of the AN/UYK-1 Standard Logram Set since all computations could be satisfactorily served by such a usage. However, a somewhat more efficient method as far as machine utilization is concerned would be to develop a small set of lograms whose usage may be anticipated by looking at the proglem details, and by the use of machine code where usage is both efficient and convenient.

Selection of a subset of the Standard Logram Set together with the addition of a few special purpose lograms will result in a coding repertoire which will be efficient insofar as speed is concerned and saving of core memory ordinarily allocated to the logram set.

A suggested set of lograms are shown below, together with the time and storage estimates. The programming estimates included herein assume the use of the set and machine code where appropriate.

Logram	Mnemonic	Time (μs)	Storage
Load Add Store	LAS	90	6
Load Subtract Store	LSS	96	6
Load Multiply Store	LMS	186	23
Load Divide Store	LDS	260	46
Load Complement Store	LCS	66	4
Sine-Cosine	SCD	612	128
Arc-Tangent	AT	555	112
Arc-Sine	AS	1562	214
Binary to BCD	BBD	983	43
BCD to Binary (Double Length)	BBN	945	67
Grey to Binary (Double Length)	GBN	468	82

4.5.4.4 Peripheral Equipment. - The Standard AN/UYK-1 Peripheral Equipment Group consists of the following devices:

TRW-140 Controller

TRW-151 Paper-Tape Reader and Reeler

TRW-161 Paper-Tape Punch

TRW-185 Input/Output Typewriter

TRW-186 Send-Receiver Set

IBM Model 024 or 026 Keypunch (modified)

The TRW-140 Controller provides a capability of on-line or off-line operations with the AN/UYK-1, reading 5, 6, 7, or 8 level paper tape of any format, reading and punching cards, transmitting to and from the typewriter and transmitting to and from a standard 5 or 8 level teletype send-receive set. Code conversion in the TRW-140 is accomplished with pre-wired insert cards. (Cards can be provided for any code.) In the proposed application the TRW-140 would control a TRW-151, TRW-161 and TRW-185.

The TRW-140 Controller

The TRW-140 Controller is a solid-state electronic swtiching and transfer device, connected to the 15-bit parallel input "C" cable of the AN/UYK-1 for use as the control and distributing exchange between the computer and peripheral accessories. The TRW-140 connects and disconnects peripheral devices and can initiate Type I and Type II interrupts. The unit can control 44 useful on-line modes of operation, 25 of which can also be performed off-line.

All TRW-140 functions are controlled by a control counter; the sequencing is determined by the positions of switches on the control panel and/or commands received from the computer.

Etched-circuit insert cards used in the TRW-140 are of the same size and construction as those used in the AN/UYK-1. Of the total of 40 circuit cards, 20 (including all flip-flops and logic cards) are functionally interchangeable with corresponding cards used on the computer. This permits reduced spares inventories and facilitates equipment maintenance. The other 20 are special level changing and control inserts related to the various accessories.

Ten decoding and encoding matrix cards provide the capability for converting the 5 through 8-bit parallel code used by the computer into any existing or foreseeable future code used by the peripheral devices, and of converting codes used by the latter into the computer code. Codes are specified by the user and code conversion elements are arranged so the user can readily change them.

An 8-bit flip-flop register accepts and holds information from the typewriter via the encode matrix, from the paper tape reader, and from the computer. Data is transferred to peripheral devices through the register, i.e., to the typewriter through the decode matrix, to the Paper-Tape Punch, and to the computer.

The TRW-151 Paper Tape Reader and Reeler

The TRW-151 uses silicon photoconductive diodes for reading up to eight channels from punched paper-tape. The unit reads at speeds of 100, 300, 750, or 1000-characters-per-second. The unit has a start time of three milliseconds and a stop time of less than one millisecond. A Tape Reeler is provided which will wind tape at a rate up to 40 inches per second in either direction.

The TRW-161 Paper-Tape Punch

The TRW-161 is a self-contained high-speed unit that operates at rates from 0 to 60 characters per second, designed to accept standard width paper tapes from 5-level to 8-level. The unit uses a wire clutch drive for each punch, providing nonsynchronous drive that can be operated at any speed as long as the minimum interval between cycles is 16-2/3 milliseconds. This enables the punch to be slaved to other equipment.

The mechanism of the punch is enclosed in a baffled oil case offering a low noise level and permitting the use of an oil mist to lubricate and cool the moving parts.

Punching is controlled by the presence or absence of nine supplied drive pulses (one for each bit level, plus one for sprocket and paper advance). Any combination of the pulses (but always including the sprocket and advance pulse) can be applied at any rate up to 60 pps.

The TRW-185 Input/Output Typewriter

The TRW-185 is an IBM 88 character standard 44-key input/output typewriter that includes automatic carriage return, remote case-shift and remote keyboard-lock.

Magnetic Tape Controller and Tape Units

The Magnetic Tape System further extends the capabilities of the AN/UYK-1 Data Processing System in applications with high-speed input and output requirements. A single Magnetic Tape System consists of one to four TRW-170 Tape Units and a TRW-192 Magnetic Tape Controller that controls them by program selection. An AN/UYK-1 Digital Computer can accommodate four Controllers, and therefore as many as sixteen Tape Units. An option to the TRW-192 Controller permits either of two computers to address a single TRW-192 and give both computers access to a common file of data. The most important user benefits of the tape system are:

Ruggedness. Controller and Tape Units are compactly packaged in a cast aluminum cabinet, virtually identical to the militarized AN/UYK-1 Digital Computer, and can be used under the same proven environments test as the AN/UYK-1. They are dripproof, highly shock- and vibration-resistant, and can operate in ambient temperatures from 0° C to 50° C. Tape Units use the Cook Electric Company Model 59 tape transport, noted for its ruggedness.

Compatibility. System permits information exchange with larger IBM computers because it is compatible with IBM tape equipment in format, photo-sense and write lock-out features.

Operational convenience. Programmed control and manual selection switches offer unrestricted addressability. Front access to tape desks and controls permit easy maintenance. Since Tape Units can be installed in any increment from one to sixteen (four per Controller), the system can economically meet auxiliary storage requirements as they arise.

Recording Format

In response to programmed commands, data can be recorded on tapes in either alphanumeric or binary mode.

In the alphanumeric mode, logical elements in the Controller split the 15-bit computer word into two 6-bit characters (the three most significant bits of the word are not recorded). Recording format is as follows:

		Most Significant	Least Significant
Bit Position	15 14 13	12 11 10 9 8 7	6 5 4 3 2 1
Tape Character	Not Recorded	1	2

In the binary mode, the controller assembles three 6-bit characters from the computer word by filling out the first character with zeros. This permits recording of the entire word, as follows:

	Most Significant		Least Significant
Bit Position	0 0 0 15 14 13	12 11 10 9 8 7	6 5 4 3 2 1
Tape Character	1	2	3

During read operations these processes (internal to the Controller) are reversed to form standard Computer words from the tape characters.

Speed, Transfer Rates, Storage Capacities

Tapes can be recorded at alternative packing densities of either 200 or 556 bits per inch (desired density is selected by a switch on the TRW-170 control panel). Speed of tape past the heads is 75 inches per second, and so results in transfer rates of 250,000 bits per second (41.7 Kc/sec) at high density, and 90,000 bits per second (15 Kc/sec) at low density.

High-speed rewind is accomplished at the rate of 225 inches per second, permitting an entire reel to be rewound in 128 seconds.

A single 2400-foot reel of tape, mounted in a single TRW-170, can store fifteen million characters when recorded at high density. This represents seven and a half million computer words in the alphanumeric mode, or five million in binary. The corresponding figures for low density operation are 5,400,000, 2,700,000, and 1,800,000.

IBM Compatibility

The Magnetic Tape System is capable of writing and reading magnetic tape which is physically identical to tape produced by an IBM 729 Mod II or IV, high or low density, tape unit operating in the binary mode. With programmed code conversion, compatible BCD tapes can be handled. In addition, the low density mode is identical with IBM Mod I tapes, and the high and low density modes of IBM Mod V. The following table illustrates the interchange capability of the TRW Tape System.

Density (Char/in)	IBM 729 Mod I	IBM 729 Mod II	IBM 729 Mod IV	IBM 729 Mod V
200	Yes	Yes	Yes	Yes
556	X*	Yes	Yes	Yes

Parity

A lateral parity digit (even or odd parity may be selected manually by a switch on the TRW-170 panel) is generated during writing and is recorded along with each six-bit character. A longitudinal parity character is written at the end of each information block.

Lateral parity is checked while writing by using a set of read heads separated from the write heads so that characters are read and parity checked 4 milliseconds after they are recorded. During read operations both lateral and longitudinal parity are checked. Detection of any parity error causes a "Parity Error" indicator to be set.

TRW-192 MAGNETIC TAPE CONTROLLER

The Controller is housed in a cast aluminum cabinet similar in size (59" high, 20-1/2" wide, 18" deep), to the AN/UYK-1 Digital Computer. It contains power supplies and logical circuits for communicating with the Computer and controlling the Tape Units.

The control panel of the TRW-192 consists of several indicators and switch/indicators that make for simple and reliable operation. The following briefly describes the functions.

Indicators

When illuminated, the indicators listed display the following conditions to the operator:

SELECT. Controller is presently "connected" to one of two Computers for use in a program.

COMP A/COMP B. Indicates which computer is presently connected to the Controller.

PARITY ERROR. Parity error detected; light is extinguished only by RESET switch or command from computer.

Switch/Indicators

The switch/indicators are pushbutton controls with back-lighted labels. When pressed, the switch/indicators listed cause the following actions:

POWER. Turns power on (and off, when pressed again), for all parts of tape system except transports. Indicator is illuminated when power is on.

*"X" indicates Mod does not have this density.

RESET. Disconnects Controller from Computer in emergencies and resets indicators used in the connection sequence. Switch stays in depressed position, and RESET indicator stays illuminated, until pressed again.

Tape Controller Selector Switch and Indicator

In systems with more than one controller, the TAPE CONTROLLER SELECTOR SWITCH serves to identify specific controllers to a computer. A computer addressing "Controller No. 3," for example, will connect only to a controller with its switch set to the "3" position. The TAPE CONTROLLER SELECTOR INDICATOR will display the number assigned to the controller.

TRW-170 MAGNETIC TAPE UNIT

The Magnetic Tape Unit is housed in a cabinet nearly identical in size (59" high, 20" wide, 16-1/2" deep), as well as in its cast aluminum construction, to that of the AN/UYK-1 Digital Computer. It contains power supplies for the transport and logical circuitry for communicating with the Computer via the Controller.

The control panel of the TRW-170 consists of several indicators and switch/indicators, that make for simple and reliable operation.

Indicators

When illuminated, the indicators listed signal the following conditions to the operator:

SELECT. Tape Unit has been selected for the current or last operation.

READY. Tape Unit is ready for read or write operation (i.e., tape is not being rewound, dust cover is on cabinet, RESET switch is not depressed—a total of eight operating conditions has been met).

LOAD POINT. Tape is positioned at load point (beginning of tape).

READ/WRITE. Tape is being read (upper half of indicator); tape is being written or erased (lower half).

FILE PROT. Tape reel currently on transport has no file-protect ring.

TAPE IND. Tape has reached end-of-tape reflective spot, or end of file mark was the last record read.

Switch/Indicators

The switch/indicators are pushbutton controls with back-lighted labels. (Whenever a switch is activated, the associated label is illuminated.)

HIGH/LOW. Selects desired density.

AUTOMATIC. Puts unit under control of TRW-192 Controller; when pressed again, puts unit under control of operator.

LOAD REWIND. Moves tape in reverse at high speed until it reaches load point, or until STOP switch is pressed. Under TRW-192 control (AUTOMATIC), switch is ineffective, though indicator is illuminated when tape is being rewound.

FWD. Moves tape forward. With unit under TRW-192 control, switch is ineffective though indicator is illuminated during forward motion.

STOP. Stops tape motion. With unit under TRW-192 control, switch is ineffective though indicator is illuminated whenever tape is not in motion while power is applied.

REV. Tape moves in reverse (at regular speed). With unit under TRW-192 control, switch is ineffective though indicator is illuminated during reverse motion (indicating the rewind operation).

RESET. Stops tape motion for emergencies, causing READY and AUTOMATIC indicators to be extinguished and the Computer to stop transferring data. When switch is pressed again, tape unit is reset, i.e., ready to respond once more to TRW-192 or operator control signals.

ODD/EVEN. Selects odd or even parity.

ON/OFF. Turns on power for tape transport (and off, when pressed again).

Tape Unit Selector Switch and Indicator

The TAPE UNIT SELECTOR SWITCH serves to identify specific tape units to the Computer for ultimate addressing by the Controller. A Controller addressing "Tape Unit No. 4," for example, will connect only to a Tape Unit with its switch set to the "4" position. The TAPE UNIT SELECTOR INDICATOR will display the number assigned to the unit.

SPECIFICATIONS

PERFORMANCE

<u>Recording Format</u>

Method:	NRZ (non-return to zero)
Number of Tracks:	7 (6 data, 1 parity)
Inter-Record Gap:	3/4 inch min.
Tape Markers:	"End of Tape," "Load Point: reflective spots
Compatability:	IBM 729 Tapes Mod I, II, IV completely compatible; Mod V compatible if recorded at less than 800 bits/inch

Storage Media	
Type:	1-1/2-mil Mylar tape
Width:	1/2 inch
Length:	2400 feet
Reels:	10-1/2 inch, IBM compatible hub with file-protect ring
Tape Speeds	
Backspace:	75 ips
Read/Write:	75 ips
Rewind:	225 ips
Start Time:	3 millisec max to ±10% nominal speed
Stop Time:	1.2 millisec max
Recording Density	
High:	556 bits/inch
Low:	200 bits/inch
Character Rate	
High Density:	41,700 characters/sec
Low Density:	15,000 characters/sec
Heads	
Spacing Between Write and Read Heads:	0.3 inch

PHYSICAL

TRW-192		TRW-170	
Height:	59 inches	Height:	59 inches
Depth:	18 inches	Depth:	16-1/2 inches
Width:	20-1/2 inches	Width:	20 inches
Weight:	400 lbs	Weight:	350 lbs
Power:	118v, 60 cycle, 900w	Power:	118v, 60 cycle, 600 watts average; 1000 watts peak

Connection to the Computer

Communication between Computer and Controller occurs via Cable C_{in} and Cable C_{out}. Under program control, the Computer can "connect" to the tape system by means of an External Function command that selects a particular tape unit. The following functions can be selected:

- Backspace one record
- Rewind tape
- Read tape alphanumeric
- Read tape binary
- Erase 8 inches of tape
- Write end-of-file
- Write tape alphanumeric
- Write tape binary
- Test tape status

When the controller accepts an External Function command, it causes the tape to start moving and a status word to be assembled and put on the lines of Cable C_{in}. Inspection and use of the status word is at the option of the programmer.

If the controller cannot accept a tape motion command, it generates a Type II Interrupt, enabling the computer to read the status word and determine the reason for the interrupt, by executing, under program control, a Type II Interrupt routine. Typical conditions that may start this process are:

1. Any command, except TEST STATUS, given when the tape unit is inoperative.

2. Any WRITE command to a file-protected tape.

3. Any WRITE command except WRITE END-OF-FILE given after the end of tape is sensed.

4. Any command given when Controller or Tape Unit is busy, i.e., REWIND, BACKSPACE, etc.

5. Any read command issued to a Tape Unit to which the last command issued was any of the WRITE commands.

In some of these situations, the final result of the interrupt routine will be an alert signal to the operator, in others a correction of the situation itself.

Data Transfer

If the command is READ, the Controller, after the tape is up to speed, assembles two or three 6-bit characters from the tape into a 15-bit word and transfers it to the computer. The transfer can be by word or block transfer logands.

If the command is WRITE, the Controller, after the tape is up to speed, receives a 15-bit word and breaks it into two or three 6-bit characters, and records them on tape. The transfer from Computer to Controller can be by work or block transfer logands initiated by a Type I Output Interrupt.

Because of IBM compatibility requirements, a delay of at least 7.5 milliseconds occurs between the time the computer issues a WRITE command and the time it starts writing, but—because of the AN/UYK-1 System's interrupt provisions— this 7.5 millisecond interval is put to good use: The Computer returns to its internal processing tasks until it receives a Type I Interrupt to initiate the actual data transfer.

Termination

In the READ mode, tape stopping action begins if the computer does not send a command to continue tape motion within 1.2 milliseconds after the last character has passed under the read heads. In the WRITE mode, the Controller initiates tape stopping action if the Computer stops sending words. Both events signal the completion of transfer of a block of data. When the tape stopping action is initiated, the Controller becomes automatically "disconnected" from the Computer after 4 milliseconds. During WRITE command, disconnection occurs 4 milliseconds after the Computer stops sending data. With a READ command, disconnection occurs immediately (3 microseconds) after the end of a block is detected.

Data Checking

Both lateral and longitudinal parity checks are kept on all information recorded on tape. To check the parity indicator after writing, only a TEST STATUS command need be executed, as the data is read-checked, simultaneously with writing.

Interpretive Routines

The magnetic tape Interpretive Routine presently has the following lograms:

Read one record into memory
Write one record onto tape
Read "n" words into memory
Skip "n" files on tape
Backspace "n" records
Backspace "n" files
Write end of file
Rewind

Additional lograms will be created as required.

Digital Plotter.

The Digital X-Y Plotter provides the AN/UYK-1 Data Processor System with a graphic display capability when coupled to the AN/UYK-1 Digital Computer. The Plotter consists of two parts:

1. A Cal Comp model 565 R Plotter

2. A Controller to provide necessary interface signals for connection with the AN/UYK-1 Digital Computer.

A roller feed mechanism allows the use of paper rolls 12 inches wide and up to 120 feet long. Single sheets of chart paper 8-1/2 x 11 or 11 x 17 inches may also be used.

The Digital X-Y Plotter receives data from the computer via Cable C. Appropriate instructions from the computer will cause the pen to move in any desired direction. This is accomplished by a lateral movement of the pen carriage for the Y axis plot and a rotary motion of the chart drum for the X axis plot. The Z axis movement is accomplished by use of a solenoid which allows the pen to be raised or lowered to the chart surface. The pen moves at a speed of 2 inches per second in either X or Y direction.

The data word may cause a 0.01-inch motion in either the X or Y axis or a 0.015-inch 45-degree slope line. A data word may also cause the pen to move up and away from the paper, or down to contact the paper. The pen may be positioned manually or under computer control. Symbols can be drawn under computer control giving unlimited characters of various sizes and shapes.

Power requirements are 250 watts at 1-5-125 volts, 60 cycle AC.

4.6 CONTROL CONSOLE AND DISPLAYS

Figure 4.1-3 of Sec. 4.1 indicates a pictorial of the AN/MSQ-16 control console. The console is designed to provide complete operator control of the AN/MSQ-16 and provides various displays to enable monitoring of the system operation.

The various operator controls available to the operator can be tabulated as follows:

General

Prime Power Distribution

Antenna Pedestal

Track Mode (slave, passive, manual)

Manual Antenna Positioning (AZ and EL)

Receiving System

1. Receiver on-off (8 bands)
2. Passive Tracking band select
3. Passive Tracking Polarization select
4. Tracking initiate
5. Receiver Parameters (8 sets)
   a) i-f bandwidth
   b) Detector type
   c) Manual gain/AGC
   d) Manual gain control
   e) r-f Attenuator control
   f) Scan on-off

g) Scan sector

h) Scan rate

i) Manual tuning

Calibration System (8 sets)

1. Mode select (auto, continuous, off)
2. Calibration generator tuning
3. Manual level control
4. Modulation select

Display Controls

1. Wide band panoramic CRT controls (2 sets)
2. Narrow band panoramic CRT controls (8 sets)
3. Wide band panoramic band select
4. Monitor numeric display select
   a) function
   b) band
5. Transfer oscillator controls
6. Counter controls
7. Analog recorder channel select (patch panel)
8. Analog recorder controls

Test Controls

1. Enter pre-test data
2. Test ready
3. Start Measurements
4. End measurements
5. Post-Test data entry
6. Data complete

7. Abort run

8. Correction

Computer

1. Manual entry typewriter

2. Various Computer controls

Communications

1. Intercom select

2. Radio

Not all of these controls need to be grouped within convenient locations of the operator, particularly those controls whose function are of a test nature or employed to select pre-test equipment parameters.

In addition to the controls tabulated above, the console will also contain various displays. These are tabulated as follows:

1. Numeric monitor display (6 decimal digits)

2. Wide band panoramic displays (2)

3. Narrowband panoramic displays (8)

4. Antenna azimuth position

5. Antenna elevation position

6. AN/USQ-23V time display

7. Frequency drift alarm (8)

8. Tracking radar, range, azimuth, elevation repeaters

9. Various indicator lights

   a) Tracking signal acquisition

   b) Elevation limit indication

   c) Intercom call light

In addition to the indicators listed above, as many as possible of the control functions previously tabulated should be of the self indicating type, i.e., push type switches which light when the function is initiated. This should apply to all the test and monitor controls and to any others which lend themselves to this approach.

The principal controls and displays which should be grouped for operator convenience, are the test controls, the monitor controls and display, the panoramic indicators, the receiver and calibration generator tuning controls and the pedestal and tracking controls. This will require a fairly large panel area and is the reason for a semi-circular grouping of the bays comprising the console.

SECTION 5

SYSTEM EXPANSION

A requirement of the study is a delineation of the expansion capabilities or growth potential of the AN/MSQ-16 system. This section describes these characteristics in terms of signal density, frequency extension, and data processing capability.

5.1 SIGNAL DENSITY

The configuration of Band 1 is such that the three signals consisting of any single frequency in segments a, b, and c may be received and recorded simultaneously while the Panoramic Receiver continues to scan the full band. In the event that the recording of more than one signal per segment should become necessary, additional manual receivers may be paralleled at the Sum Channel multicoupler outputs. Since passive tracking can only operate on one signal at a time there is no requirement for expansion of the difference channels. The multicoupler might be made to remain passive by the use of several 3-db couplers in a cascading pyramid, but the inclusion of additional preamplifiers would soon be needed to offset the resulting deterioration of initial sensitivity. The Precision Level function should remain as described; its use would be restricted to one signal at a time within its tuning range, at the discretion of the operator. The continuous recording of AGC level would be verified from time to time by the operator in changing the frequency of the calibration generator as needed. Adding a calibration generator for each additional manual receiver is not practical since the Calibration Generator Array is to be located in the Antenna Pedestal.

Extension of Bands 2 through 6 to include additional receiver channels to enable the simultaneous measurement of more than one signal within each band, requires the duplication of the sum channel, with a separate local oscillator. This would also provide the capability of simultaneous panoramic surveillance of the band and signal amplitude measurement. Since full bandwidth r-f pre-amplifiers are employed, signal splitting between channels can be accomplished at the amplifier output with only a small loss in channel sensitivity.

One approach to providing a limited expansion capability would be to employ the difference channel as a sum channel, assuming that passive tracking is not being employed in that particular band. This would require the addition of a local oscillator to enable the channels to be tuned to different frequencies; however, the modifications to the existing difference channel receiver would be minor. A patch board system could be employed to convert from one configuration to the other.

5.2 EXTENDED FREQUENCY COVERAGE

The expansion of the AN/MSQ-16 to provide extended frequency coverage is quite feasible providing that the additional coverage is at higher r-f frequencies. Due to the required increase in antenna size, it is not considered practical to lower the frequency coverage below 100 MC and maintain the same performance.

The antenna and receiver configurations for use at higher frequencies would be quite similar to the configuration of Band 6. The manner in which higher frequency bands would be divided is determined by the bandwidth of available microwave components. The next highest band which could be considered for the AN/MSQ-16 would cover the range of 18 KMc to 26 KMc. TWT amplifiers are available for this band. However, it can be expected that the sensitivity will be less, as TWT noise figure in this frequency range are on the order of 15 db. The next higher frequency band that can be considered is the frequency band of 26 KMc to 40 KMc. TWT amplifiers are also available, together with BWO oscillators that can be employed as the receiver local oscillator.

The addition of higher frequency bands will have little effect upon the antenna pedestal, as the antenna sizes would be relatively small. No increase in the data processing requirements is expected as more than adequate capacity is available in the present configuration. The control console would require the addition of receiver controls; however, it is expected that the panoramic displays provided can be band switched to enable their use with the new bands, as it does not seem very probable that all bands would be in simultaneous use.

5.3 DATA PROCESSING EXPANSION

The computer system may be expanded to include readily integrated additional core memory in modular units, to accommodate increased input data rates and computational requirements. The system may be easily expanded to provide data to multiple graphic or storage devices, such as additional magnetic tape units. Data may be remoted to different operational areas. If a large volume of data must be visually presented, a line printer is available for immediate integration in the system.

The subsystem may be readily accommodate an additional Digital Interface Buffer to communicate with the computer by means of Channel "B" of the computer, thereby doubling its input capabilities. The only modification required would be to the operational program to distinguish the source of data. Recording of the larger volume of data can be easily accommodated by magnetic tape units at recording rates of 15,000 to 41,700 characters per second.

The computer may therefore service two data acquisition systems during simultaneous flight operations. Data from each data system can be recorded on different tape recorders with monitored data displayed on the typewriter and/or the high speed line printer. Remote light displays may be implemented and controlled from the computer with the computer providing the necessary decoding.

SECTION 6

SURVEY OF AVAILABLE EQUIPMENT

This section reports the results of a survey of the commercial availability of devices which might find a place in the AN/MSQ-16 system. The discussion considers antennas, rotating joints, pedestal, receivers, and calibration generators separately.

6.1 ANTENNAS

A preliminary specification describing the AN/MSQ-16 antenna requirements was submitted to various antenna manufacturers.

The manufacturers were requested to review the specification and indicate if they presently had equipment available which would approach the AN/MSQ-16 requirements. The response received from the manufacturers contacted is indicated by the code number in the response column. This code is as follows:

1. No reply.
2. Reply, but do not have related equipment.
3. Reply to the effect that a proposal for custom-built equipment would be submitted upon invitation, or that future collaboration would be welcomed.
4. Reply suggested available equipment.

Antenna Manufacturers Contacted	Response
Advanced Development Labs, Inc.	1
Aero Geo Astro Corp.	2
Ainslie Corp.	2
American Electronic Laboratories, Inc.	1
Andrew Corp.	2
Antlab, Inc.	2
CHU Associates	1
Diamond Antenna & Microwave Corp.	4
Electronic Specialty Co., Kennedy Antenna Division	4

Antenna Manufacturers Contacted	Response
Granger Associates	2
HRB-Singer Inc.	2
I-T-E Circuit Breaker Co., Special Products Division	2
Radiation, Incorporated	2
Rantec Corporation	2
Sperry Microwave Electronics Co., Clearwater, Florida	2
Technical Appliance Corp.	3
Telerad Division, The Lionel Corp.	3
Antenna Systems, Inc.	1
Litton Systems, Maryland Division	1
General Electronics Laboratories Inc.	2
Dynatronics, Inc.	1
Dorne and Margolin, Inc.	4
Alford Mfg. Co.	1
Cubic Corp., Industrial Division	3

6.2 ROTATING JOINT

A preliminary specification for the rotating joint was also submitted to various manufacturers. These are listed below, together with their response as indicated in the previous section. It should be noted that the preliminary specification described a 24-channel r-f rotating joint with four channels for each frequency band. As the study progressed, it was concluded that an i-f rotating joint should be employed. The listed manufacturers were not re-contacted to indicate this change.

Manufacturers Contacted	Response
Actuation Research Corp.	1
Advanced Development Labs, Inc.	1
Airborne Instruments Laboratory	4
Airtron Co.	1
Applied Microwave Electronics Inc.	2
Diamond Antenna & microwave Corp.	1
Douglas Microwave Co.	4
Gabriel Co., Gabriel Electronics Division	1
Hughes Industries	1
Microwave Development Laboratories, Inc.	1

Manufacturers Contacted	Response
Sage Laboratories, Inc.	1
Sanders Associates, Inc.	1
Scientific - Atlanta, Inc.	2
Sperry Microwave Electronics	1
Telerod Division, The Lionel Corp.	3
Waveline, Inc.	2
Dorn & Magolin, Inc.	2
General Electronics, Lab., Inc.	2

6.3 PEDESTAL

As indicated in the previous sections, a preliminary specification describing the AN/MSQ-16 pedestal requirements was submitted to various manufacturers. These are listed below together with their response.

Manufacturers Contacted	Response
Advanced Structures Co.	1
American Electronic Laboratories, Inc.	1
Andrew Corp.	1
Antlab, Inc.	1
Avien Inc., Antenna Div.	4
Blaw Know Co., Advanced Products Div.	1
Canoga Electronics Corp., Engineering Div.	1
Gorham Electronics Co.	2
I-TOE Circuit Breaker Co., Special Products Div.	1
Page Communications Engineers, Inc.	1
Radiation, Inc.	1
Rohn Manufacturing Co.	1
Rohr Corp.	4
Scientific - Atlanta, Inc.	4
Steel Products Engineering Co.	1
Technical Appliance Corp., Defense & Industrial Div.	4
Antenna Systems, Inc.	1
Reeves Instrument Corp.	2

6.4 RECEIVERS

The following is a list of manufacturers contacted in June of 1963, in an effort to determine whether they offered equipment which might meet or be made to meet the specifications of the AN/MSQ-16.

Manufacturers Contacted	Response
Airborne Instrument Labs	2
Airtron	1
Alfred Electronics	2
American Electronic Lab, Inc.	2
Antlab, Inc.	2
Applied Research, Inc.	1
Applied Technology, Inc.	3
Bendix Corp. (Bendix Pacific Div.)	2
Communications Electronics, Inc.	1
Dynatronics, Inc.	2
E-H Research Labs, Inc.	3
Electronic Research Associates	2
Electronic Specialty Corp. (Technicraft Div.)	2
Empire Devices, Inc.	2
Fairchild Camera & Instrument Corp. (Defense Products Div.)	1
General Instrument Corp. (Radio Receptor Div.)	1
General Precision, Inc. (GPL Div.)	1
Instruments for Industry, Inc.	2
International Microwave Corp.	1
Jerrold Electronics Corp.	2
Lear-Siegler, Inc. (Astronics Div.)	1
LEL, Inc.	1
Litton Industries, Inc.	1
Loral Electronics	3
Manson Labs, Inc.	2
Martin-Marietta Corp. (Electronic Systems & Products Div.)	2
Melabs	4
Microphase Corp.	2
Micro - Radionics, Inc.	3

Manufacturers Contracted	Response
Panoramic Electronics, Inc.	1
Paradynamics, Inc. Dept. MW	1
Philco Corp., Western Development Labs	3
Polarad Electronics Corp.	2
Radiation, Inc.	1
Rantec Corp.	2
Resdel Engineering Corp.	2
Scientific - Atlantic, Inc.	4
Singer-Metrics, Div. - Singer Mfg. Co.	4
Stoddart Aircraft Radio Co., Inc.	4
Sylvania, Electronic Systems Div.	1
Vitro Electronics	1
Weinschel Engineering Co., Inc.	1

Companies giving Response #4 are listed herewith, together with their suggested equipments.

Melabs	Model Type RSA ( ) - 2
Scientific - Atlantic	Model 1600 Wide Range Receiving System
Singer - Metrics	SPA - 42 Spectrum Analyzer
Stoddart Radio	NM - 62 A Interference and Field Intensity Meter.

The Stoddart receiver is limited to a slow tuning rate due to motor-drive on first L.O. klystrons. Tuning range is 1 to 10 Gcs. A forthcoming adapter will extend this upward, but nothing is anticipated which will include the 0.1 to 1.0 Gcs band. Operation is restricted to one band at a time.

The Singer-Metrics Spectrum Analyzers have manual-tuning only, with narrow-band (1 - 80 Kcs), lin-log i-f amplifier, klystron first L.O. requiring slow mechanical tuning for full-band sweep. These units are excellent in their own intended application, that of detailed spectrum analysis of any single signal within the frequency range 10 - 44,000 Mcs with a maximum sweep sector of 100 Mcs. It would be impractical to consider incorporating these analyzers into the AN/MSQ-16.

Scientific-Atlantic Model 1600 wide-range receiving system has a single triode cavity first local oscillator which tunes from 2.0 to 4.1 Gcs. The first mixer responds to harmonics of this L.O. up to the 25th. No preselection is employed for image or spur rejection. Overall i-f bandwidth is 0.5 Mcs. The second i-f is swept by modulating the second L.O. at a 1-Kcs rate over an apparent range of ± 3.5 Mcs, the width of the first i-f. This system does not appear to be adaptable to the AN/MSQ-16 complex.

The Melabs receivers are the most suitable of the available equipments. In Bands 2 through 6, that is, 1 to 18 Gcs, they employ TWT pre-amps, variable-sector sweeping BWO's, variable bandwidths, multiple-purpose detectors, and both pan-frequency and video "A" scope displays. Each band has an independent tuner and is capable of swept or non-swept operation. Only one i-f channel is included, however, which restricts operation to one signal at a time. The receiver for Band 1 incorporates a display unit that gives pan frequency only; it is used in the swept-mode exclusively. Nevertheless, these receivers offer an excellent basis for expansion to the full AN/MSQ-16 system requirements.

Manual receivers for Band 1 may be selected from several currently available models such as the Model 770-A of Communications Electronics, Inc., or the AMD-21-4, RFT-30-260 and RFT-250-1000 of Nems-Clark. The CEI unit would require extension down to 100 Mcs from its present lower limit of 235 Mcs.

6.5 CALIBRATION GENERATORS

The following is a list of companies contacted in regard to the Calibration Generator Array. The responses were all negative except that Alfred Electronics at least had a complete line of suitable self-levelling generators, though they are not ruggedized and are primarily for laboratory use. Hewlett-Packard proposed an excessively expensive system for Bands 2 and 3.

Alfred Electronics

Bay State Electronics Corp.

Dymec, a Division of Hewlett-Packard Co.

Empire Devices, Inc.

FXR Division of Amphenol - Borg Electronics

Lavoie Laboratories, Inc.

Paradynamics, Inc.

Polarad Electronics Corp.

Rantec Corp.

Sperry Microwave Electronics Co.

It appears that the Calibration Generator Array will require an original design effort or extensive modification of existing equipment.

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APPENDIX I

RELIABILITY DATA

1.0 INTRODUCTION

This appendix presents a discussion of preliminary reliability data associated with Operation Central An/MSQ-16 (XW-2).

The broad considerations of the AN MSQ-16 study performed and the nature of the results obtained have precluded detailed equipment reliability investigations. Thus, this appendix concerns a general perspective of the 200-hour mean-time-between-failure (MTBF) requirement and some specific methods required for its attainment.

2.0 DISCUSSION

The basic model for the AN/MSQ-16 (system) reliability is based upon:

$$R_s = \prod_{n=1}^{5} R_i \qquad (1)$$

where,

R_s = system reliability during any one operational mode

R_i = reliability of the i^{th} subsystem during operation

For reliability modeling purposes, the system is divided into five (5) major subassemblies as shown in Fig. II-1. Multiplication in equation (1) is thus made over the range one to five.

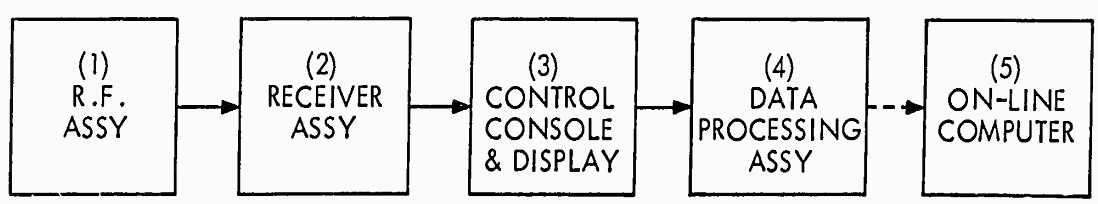

Figure II-1. AN/MSQ-16 System Subassemblies

The general model is the parametric set of equations comprised of equation (1) and those defining R_i. R_i is given in terms of its unit groups as they are serially and/or redundantly oriented to the subsystem function. That is, R_i may be itself of a serial or redundant nature or a combination of both. The underlying failure distribution of R_s can be considered exponential with time due to the relatively large size (quantity of components) and complexity of the AN MSQ-16 system.

2.1 On-Line Computer Reliability (R_s)

It is proposed that the on-line computer be a Thompson-Ramo-Wooldridge Model AN/UYK-1. Investigations have shown it to possess the desirable operational characteristics for this function. Analysis of data resulting from seventy (70) such computers operating in field conditions have revealed the unit to possess an MTBF of no less than 1100 hours ($\lambda = 0.909 \times 10^{-3}$ hrs) at 50% confidence level.

2.2 Reliability of Functions One Through Four (R_1, R_2, R_3, R_4)

It has not been practical to gather detailed data on functions one through four at this point in the system development. However, much can be said of the feasibility of their attaining sufficient reliability to insure the attachment of the system reliability goal.

2.2.1 Estimated Reliability Based on Parts Count

Recognizing that within the functions not all component parts are serially related to system failure, if it is assumed they are, worse case condition arises wherein a minimum reliability figure can be obtained. This serial assumption is made at this point.

MIL-R-27070 specifies that in the event no specific MTBF requirement is given, the equipment reliability shall be defined by the following formula:

$$1/\mathrm{MTBF} = Fr = 30 \times 10^{-6} \times N_t + 15 \times 10^{-6} \times N_m$$

$$2 \times 10^{-6} \times N_s + 0.5 \times 10^{-6} \times N_c$$

where,

N_t = Total number of tubes (envelopes)

N_m = Total number of motors and relays

N_s = Total number of semiconductors

N_c = Total number of remaining electrical and electromechanical parts.

Table II-1 presents an estimated parts count of functions one through four.

TABLE II-1

	R-F Assy.	Receiver Assy.	Data Processor	Control Console	Total
Tubes (envelopes)	18	32	-	9	59
Relays and Motors	24	12	10	26	72
Semiconductors	100	1200	250	600	2150
Other	1500	6500	2500	4200	14,700

Applying these figures to the formula, the following results are obtained:

$$F_r = 30 \times 59 \times 10^{-6} + 15 \times 72 \times 10^{-6} + 2 \times 2150 \times 10^{-6}$$
$$+ \ 0.5 \times 14,700 \times 10^{-6} \text{ failures/hour.}$$
$$= 14,500 \times 10^{-6} \text{ failures/hour.}$$
$$\text{MTBF} = 1/F_r = 71 \text{ hours/failure}$$

2.2.2 Improving the Parts Count Reliability Figure

Comparison of this figure (71 hrs) to the required 200 hours is, upon first impression, somewhat disappointing. However, after consideration of several important factors, it can be seen that the equipment is truly capable of much better reliability performance.

In the first place, examination of the formula reveals that tubes are considered to exhibit the mean failure rate of 20 x 10^{-6} failures/hour (3.0%/1000 hours). Actually, much data has been accumulated to indicate that a better mean estimate is 15 x 10^{-6} failures/hour (1.5%/100 hours)(1) (2) (3) (4).

Similarly, it is found that the 15 x 10^{-6} applied by the formula for motors and relays can be better estimated at 5 x 10^{-6}; 2 x 10^{-6} for semiconductors replaced by 0.8 x 10^{-6}; and 0.5 x 10^{-6} for remaining items replaced by 0.2 x 10^{-6}.

When the revised failure rates are applied to the formula, a much improved MTBF results.

$$\text{MTBF}' = 10^{6}/ \ [illegible] \ 59 + 5 \times 72 + 0.8 \times 2150 + 0.2 \times 14700 \quad 170 \text{ hours.}$$

Secondly, it must be kept in mind that the estimated failure rates given are mean results of a wide range of applications, part quality, assembly and checkout techniques, etc. Hence, for any particular application, the mean figure may be quite unrealistic. If, during actual hardware development, precautions are exercised to eliminate those design and part application circumstances conducive to accelerated failure rates (reliability engineering tasks), then the total effect will be a reduction in the mean failure rates for system operation. Just exactly what reliability tasks are required depends on many circumstances, and it is necessary to exercise considerable care in their selection in order to insure the proper trade-offs among many important factors; some of which are:

a. Existing reliability of "off-the-shelf" equipment

b. Newly designed equipment reliability

c. System reliability requirements

d. Methods of reliability prediction and demonstration

For instance, it would serve little net gain to impose a rigorous, comprehensive set of reliability tasks on a manufacturer of a non-critical equipment, or on a manufacturer who has, through time and trial, perfected his equipment, design and can prove its performance suitability. Notwithstanding this, if certain minimum reliability requirements are imposed (e.g. requiring use of standard parts and adequate application derating), the MTBF figure can be advanced a conservative thirty (30) percent, yielding

$$\text{MTBF}'' = 1.33 \times 170 = 226 \text{ Hours}$$

As a third consideration, reliability analyses on the part of the AN/MSQ-16 equipment contractor can affect considerable gains in the system MTBF. For instance, by performing a reliability allocation analysis on a sybsystem and modular basis, critical system links can quickly be identified. Subsequently, heavier reliability improvement emphasis can be placed on the module(s) in question. If relatively large increases in any subsystem or module are indicated by the allocation analysis, such remedies as "high reliability" parts, circuit redundancy, etc. are available.

Having considered the above discussion, the conclusion is reached that an MTBF of 300 hours for the combined effects of functions one through four does not appear unreasonable and can be affected without undue costs or time delays. For the complexity of the equipment involved and nature of its function(s), this figure can probably be met without extensive use of "high-reliability" parts or gross system redundancies.

2.3 AN/MSQ-16 System Reliability (R_s)

Combining the failure rate of the computer with that estimated for the remaining functions gives the following results:

$$R_s = \sum_{i}^{5} R_i = e^{-(\lambda_{1234} + \lambda_5)\,t}$$

$$R_s = e^{-(4.24 \times 10^{-3})\,t}$$

for an eight (8) hour mission

$$R_s = e^{-0.0339}$$

$$= 0.9666$$

And...

MTBF $\approx$ 236 hours/failure

References:

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APPENDIX II

MAINTAINABILITY DATA

1.0 INTRODUCTION

This appendix discusses the maintainability aspects of the AN/MSQ-16 system. It is noted that, at best, only preliminary considerations can be made at this level of system definition since little actual hardware configuration has been solidified.

2.0 DISCUSSION

Since maintainability is closely linked with physical configuration (physical convenience), it is proper to discuss the AN/MSQ-16 set in two parts: 1) the antenna and r-f equipment located in, and on, the antenna pedestal and 2) the receiving, translating and output equipment located in the control house.

2.1 Antenna Pedestal Equipment (R-F Group)

The antenna pedestal will contain the antennas, the servo drive package, calibration generators and the r-f preamplifier and tuning units. From strictly a maintainability viewpoint, this equipment would ideally be located centrally in the pedestal at ground elevation. However, the design factors of performance efficiency preclude this and instead, the majority of equipment will be located above ground elevation. Hence, if mean-time-to-repair (MTTR) is to be held to a minimum, very careful attention must be paid to certain maintainability factors. It is not appropriate in this discussion to make a detailed list of all factors which must be considered, however, some of the more important ones are given below.[1]

a) Construct convenient, safe access ladders, walks, etc., and provide balance rails, work shelves and test equipment hangers at maintenance stations throughout the antenna assembly.

b) Place a maintenance work station of all units requiring calibration, repair or replacement. Locate same so that the maintenance man is performing work in a "head-up" position.

c) Utilize modular design to the maximum extent possible.

d) Minimize permanent interconnections to the extent consistent with the reliability factors. Employ quick disconnect devices.

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(1) For an excellent maintainability factors check list the reader is referred to: E. T. A., "Maintainability Bulletin No. 1", Dec. 1960.

e) Minimize tool requirements such as wrenches, screwdrivers, etc., replacing with wing nuts, control knobs, etc.

f) Provide in-circuit monitoring devices such as voltmeters, ampmeters, etc., at critical performance points.

g) Provide communications links between antenna maintenance stations, ground elevation, and control house.

While the density of the electronic and electromechanical parts in the antenna pedestal group is significantly large ($\approx$1640 parts), consideration of the above factors along with the advantageous design of integral calibration generators in the r-f set should give rise to an MTTR of less than one hour (excluding repair of replaceable modules and units).

2.2 Main Equipment Group (receiving, translating and output).

2.2.1 Comparing this equipment group to that of the antenna pedestal, it is seen that while the total parts count is approximately 14 times greater ($\approx$ 22500 parts) and the performance functions more detailed, there are many factors which tend to keep the MTTR down inapportionately to the parts ratio.

Serviceability: The equipment is conveniently accessible. Test equipment can be utilized extensively. Spare parts and modules are easily substituted. Size and weight restrictions are not severe, hence, more maintainability can be designed into the equipment. Automatic test and parameter monitoring devices appear practical.

Design Function: Digital logic is used extensively in this equipment group. This factor alone accounts for vast savings in detecting the malfunction and subsequently located the failure. Failures are more likely to be catastrophic and their replacement is more easily affected by a modular replacement.

2.2.2 As an indicator of what maintainability can be achieved, data obtained on the AN/UYK-1 computer indicates an MTTR of 15 minutes in actual field conditions. Since the machine contains approximately 6000 parts, this is equivalent to 41.7×10^{-6} hours/part maintenance time. Considering the computer to be well developed and maintenance debugged, it is not justifiable to use this figure on the remaining equipment. However, allowing a conservative 100% degradation factor ($2.0 \times 41.7 \times 10^{-6}$) and applying the modified figure to the remaining parts, the following results are obtained.

$$\text{MTTR} = 83.4 \times 10^{-6} \times 16{,}399 = 1.37 \approx 1.5 \text{ hours}$$

2.3 Mean-Time to Repair (MTTR) for the AN/MSQ-16

MTTR for the entire AN/MSQ-16 system (pedestal group and main equipment group) can be obtained by combining the separate MTTR's together through use of MTBF figures as follows:

$$MTTR = \frac{\dfrac{MTTR_{(1)}}{MTBF_{(1)}} + \dfrac{MTTR_{(2)}}{MTBF_{(2)}}}{\dfrac{1}{MTBF_1} \qquad \dfrac{1}{MTBF_2}}$$

where:

$MTTR_{(1)}$ = MTTR of pedestal group

$MTBF_{(1)}$ = MTBF of pedestal group

$MTTR_{(2)}$ = MTTR of main equipment group

$MTBF_{(2)}$ = MTBF of main equipment group

$MTBF_{(1)}$ and $MTBF_{(2)}$ are estimated from figures in Appendix II of this document in proportion to total parts density as follows:

$$\frac{1}{MTBF_{(1)}} = \frac{1640}{22400} \times \frac{1}{236}$$

$$MTBF_{(1)} = 3220 \text{ HOURS}$$

and

$$\frac{1}{MTBF_{(2)}} = \frac{20760}{22400} \times \frac{1}{236}$$

$$MTBF_{(2)} = 255$$

Thus:

$$MTTR = \frac{\dfrac{1}{2360} \qquad \dfrac{1.5}{255}}{\dfrac{1}{2360} \qquad \dfrac{1}{255}} \approx 1.5 \text{ HOURS}$$

APPENDIX III

METHOD OF COMPUTING ORIENTATION OF AN R-F VECTOR

Problem: Determination of the orientation of an r-f vector emanating from an airborne transmitting antenna by measuring the r-f field strength at a ground site. The following method takes into consideration a spherical earth and accounts for all elements of the aircraft aspect.

Figure IV-1 represents the geometry and co-ordinate systems involved.

The coordinate system of the site is oriented such that the Y axis is in the direction of geographic north. The coordinate system of the aircraft is oriented such that the Y_p'' axis coincides with the roll axis of the aircraft and the X_p'' axis coincides with the pitch axis of the aircraft.

The known parameters at any given time are:

R_s = slant range from site to aircraft

El = elevation angle of receiving antenna at the site

R_e+h = radius of earth compensated for elevation above sea level

Alt = altitude of the aircraft with respect to elevation of site above sea level

Az = bearing of aircraft with relation to the site

Using the above parameters, and known relations between the sides and angle s of any plane triangle, and referring to Figure IV-2, the following derivation is accomplished.

The relation

$$\frac{c}{\sin C} = \frac{a}{\sin A}$$

can be solved for C, the geocentric angle between the site and the aircraft. Thus,

$$C = \arcsin\left(\frac{c \sin A}{a}\right),$$

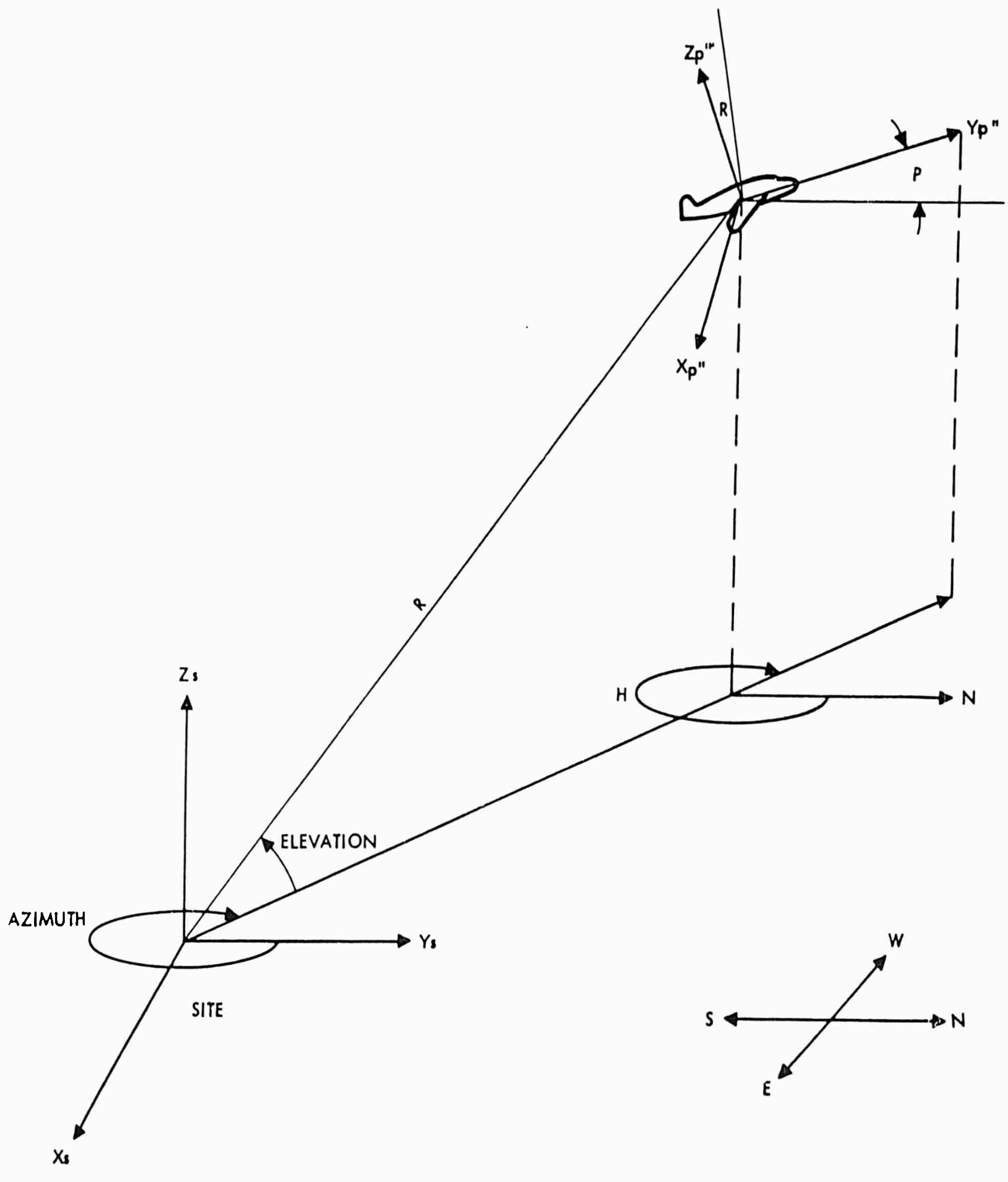

Figure IV-1. Geometry for R-F Vector Calculations

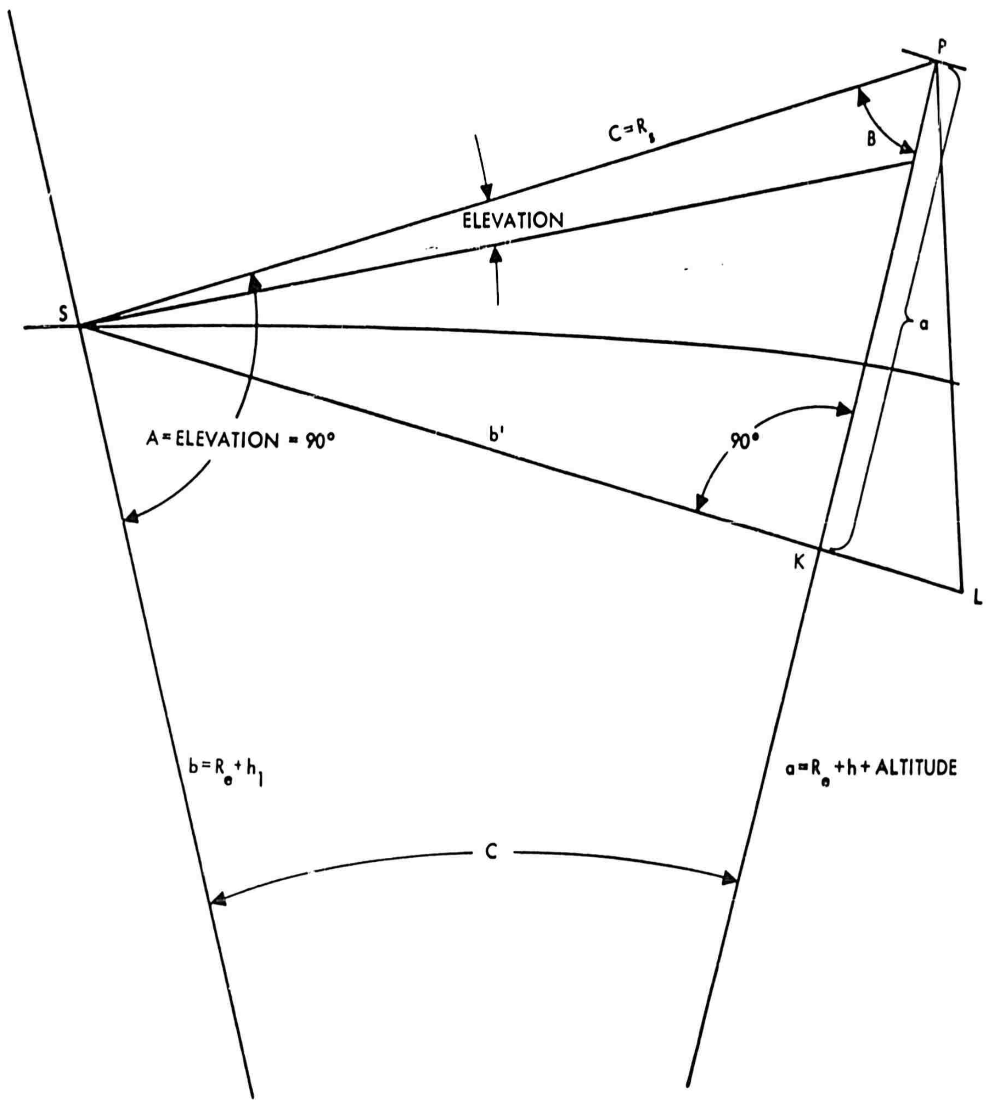

Figure IV-2. Geometry for Earth's Curvature Correction where

$$A = 90° + El,$$

$$a = R_e + h + Alt,$$

$$c = R_s$$

Having found C, B is determined from the simple relation $A + B + C\ 180°$; or,

$$B = 180° - (A + C).$$

The distance b' is then calculated, where b' is one side of a right triangle with hypotenuse R_s and an acute angle B. Hence,

$$b' = R_s \sin B,$$

or

$$b' = R_s \sin \left[180° - A - \arcsin\left(\frac{c \sin A}{a}\right)\right].$$

The length of the side adjacent to B is given by

$$a' = R_s \cos B,$$

or

$$a' = R_s \cos \left[180° - A - \arcsin\left(\frac{c \sin A}{a}\right)\right].$$

Setting up a three-dimensional (rectangular) coordinate system with the site as the origin, the Y axis in the direction of north, and the Z axis perpendicular to b' at the origin, the following coordinates of the aircraft in the coordinate system of the site may be specified:

$$X_s = b' \cos (450° - Az),$$

$$Y_s = b' \sin (450° - Az),$$

$$Z_s = a'$$

Translating the origin to the point just defined,

$$X_p = 0 - X_s,$$

$$Y_p = 0 - Y_s,$$

and

$$Z_p = 0 - Z_s.$$

The next step is to rotate this translated coordinate system into the coordinate system of the aircraft which is defined by heading, roll, and pitch. From the general equations of rotation,

$$a = a' \cos \theta - \beta' \sin \theta,$$

$$\beta = a' \sin \theta + \beta' \cos \theta,$$

we can write

$$a' = a \cos \theta + \beta \sin \theta,$$

and

$$\beta' = \beta \cos \theta - a \sin \theta,$$

which allows writing the new coordinates by inspection. Rotating about the Z_p axis through an angle equal to the negative of the heading,

$$X_p' = X_p \cos(-H) + Y_p \sin(-H),$$

and

$$Y_p' = Y_p \cos(-H) - X_p \sin(-H).$$

Rotating about the Y_p' axis through an angle equal to the roll,

$$X_p'' = X_p' \cos R + Z_p \sin R,$$

and

$$Z_p' = Z_p \operatorname{Cos} R - X_p' \sin R.$$

Rotating about the X_p'' axis through an angle equal to the pitch,

$$Y_p'' = Y_p' \cos P + Z_p' \sin P,$$

and

$$Z_p'' = Z_p' \cos P - Y_p' \sin P.$$

The expressions for X_p'', Y_p'', Z_p'' define the coordinates of the site in the coordinate system of the aircraft and, by performing the proper substitutions, the following results are obtained:

$$X_p'' = -R_s \cos\left[90° - El - \arcsin\left(\frac{R_s \sin(90° + El)}{R_e + h + Alt}\right)\right] \sin R -$$

$$- R_s \sin\left[90° - El - \arcsin\left(\frac{R_s \sin(90° + El)}{R_e + h + Alt}\right)\right] \times$$

$$\times \cos R \left[\cos(450° - Az)\cos(-H) + \sin(450° - Az)\sin(-H)\right].$$

$$Y_p'' = -R_s \cos\left[90° - El - \arcsin\left(\frac{R_s \sin(90° + El)}{R_e + h + Alt}\right)\right] \sin P \cos R +$$

$$+ R_s \sin\left[90° - El - \arcsin\left(\frac{R_s \sin(90° + El)}{R_e + h + Alt}\right)\right] \times$$

$$\times \left[\cos(450° - Az)\left\{\sin(-H)\cos P + \cos(-H)\sin P \sin R\right\} +\right.$$

$$\left. + \sin(450° \quad Az)\left\{\sin(-H)\sin P \sin R - \cos(-H)\cos P\right\}\right].$$

$$Z_p'' = -R_s \cos\left[90° - El - \arcsin\left(\frac{R_s \sin(90° + El)}{R_e + h + Alt}\right)\right] \cos P \cos R +$$

$$+ R_s \sin\left[90° - El - \arcsin\left(\frac{R_s \sin(90° + El)}{R_e + h + Alt}\right)\right] \times$$

$$\times \left[\cos(450° - Az)\left\{\cos(-H)\cos P \sin R + \sin(-H)\sin P\right\} +\right.$$

$$\left. + \sin(450° - Az)\left\{\sin(-H)\cos P \sin R - \cos(-H)\sin P\right\}\right].$$

It is now a straightforward procedure to determine the aspect angle and depression angle after the coordinates have been defined.

The coordinate systems have been chosen such that the longitudinal (roll) axis of the aircraft is the Y_p'' axis, and the X_p'' axis lies in the plane of the wings (pitch).

Knowing X_p'' and Y_p'', the angle between the X_p'' axis and a line drawn between the origin and the site is determined. This is the normal mathematical convention of measuring angles in a counterclockwise direction from the X axis. Hence,

$$\theta = \arctan \frac{Y_p''}{X_p''}, \qquad 0 \leq \theta \leq 360^\circ.$$

However, the aspect angle is the relative bearing of the site as measured clockwise from the nose of the aircraft, leading to

$$\text{Aspect angle} = (450^\circ - \theta).$$

The depression angle is determined by use of the Pythagorean theorem and use of a simple trigonometric formula.

$$\text{Depression angle} = \arctan \left(\frac{Z_p''}{\sqrt{(X_p'')^2 + (Y_p'')^2}} \right).$$